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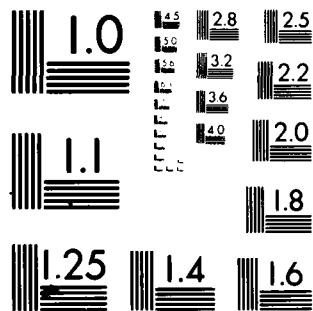
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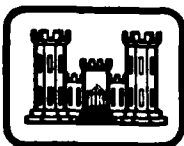
September 1981

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SURFACE DRAINAGE DESIGN FOR AIRFIELDS AND HELIPORTS IN ARCTIC AND SUBARCTIC REGIONS

Edward F. Lobacz and Kenneth S. Eff

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Cold regions	
Construction	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents engineering guidance and design criteria for drainage facilities at Army and Air Force airfields and heliports in arctic and subarctic regions. Attention is given to hydrologic criteria, icings, environmental impact, storm drains and design computer programs. A design example and a list of 40 references are included in two appendixes.

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PREFACE

This report presents recently revised design criteria for drainage facilities at Army and Air Force airfields and heliports, adapting previously used U.S. hydraulic design criteria to the special conditions prevailing in arctic and subarctic regions. It has been prepared with the final objective of publication as an official engineering manual (Department of the Army Technical Manual TM5-852-7 and Department of the Air Force Manual 88-19, Chapter 7). It has been issued as a CRREL Special Report to promote dissemination of this knowledge to engineers concerned with drainage design in cold regions.

Valuable input for revision of these criteria was received from the U.S. Army Engineer Division, North Pacific; the U.S. Army Engineer District, Alaska; the Alaskan Air Command; the State of Alaska Department of Transportation and Public Facilities, Central Region; the State of Alaska Department of Transportation and Public Facilities, Division of Aviation Design and Construction; the Municipality of Anchorage, Department of Public Works; and Bolter-Parish-Trimble Ltd., Consulting Engineers, Edmonton, Alberta, Canada.

The authors wish to thank Kevin L. Carey and the U.S. Army Engineer Division, Huntsville (HNDED-SM) for technically reviewing the contents of this report.

Acknowledgement is made to the originators of illustrations and tables from copyright sources and other publications that appear in the text. Special thanks is offered to Harold Larsen and Donna Harp of the Technical Information Branch for their invaluable assistance in preparation of illustrations and typing of this publication.

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EDWARD F. LOBACZ

and

KENNETH S. EFF

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CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM Metric Practic Guide (E380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E380).

Multiply	By	To Obtain
inch	25.4*	millimeter
inch	2.54*	centimeter
foot	0.3048*	meter
mile	1.6093*	kilometer
mile^2	2.589998	kilometer^2
acre	0.4046873	hectare
foot/minute	0.3048*	meter/minute
foot/second	0.3048*	meter/second
foot^3/second	0.02831685	meter^3/second

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* Exact

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SECTION 1. GENERAL

1-1. **PURPOSE AND SCOPE.** This report presents discussions and examples that give a better understanding of problems in the design of drainage facilities, and outlines convenient methods of estimating design capacities for airfield and heliport drainage facilities in arctic and subarctic regions. Although the design data presented have been developed primarily for drainage conditions in North America, they are also generally applicable to other arctic and subarctic regions. The data are applicable to Air Force and Air National Guard airfields and to Army airfields and heliports. For roads and built-over areas[3][31], different methods and design rates of rainfall are used in computing runoff amounts and in determining the size of storm drains, culverts and other drainage facilities. However, the general information in this report on icings and special design considerations for arctic and subarctic conditions is applicable. Criteria in TM 5-820-4[7] together with design storm indexes determined from Figure 2-1 will be used for design of drainage facilities for other than airfields and heliports.

1-2. **DEFINITIONS.** The following specialized terms are used in this report. For additional definitions and descriptions see TM 5-852-1.[10]

    a. **Arctic.** The northern region in which the mean temperature for the warmest month is less than 50°F (10°C) and the mean annual temperature is below 32°F (0°C). In general, the Arctic coincides with the tundra region north of the limit of trees.

    b. **Subarctic.** The region adjacent to the Arctic in which the mean temperature for the coldest month is below 32°F, the mean temperature for the warmest month is above 50°F, and in which there are less than 4 months having a mean temperature above 50°F. In general, the subarctic land areas coincide with the circumpolar belt of dominant coniferous forests.

1-3. **DESIGN OBJECTIVES.** The design capacity of the airfield or heliport surface drainage system should be adequate to accomplish the following objectives as satisfactorily as is economically feasible, with due consideration of the mission and importance of the particular airfield or heliport, effects of icings, and environmental impact.

a. **Surface Runoff from Design Storm.** Surface runoff from the selected design storm will be disposed of without damage to facilities, undue saturation of the subsoil, or significant interruption of normal traffic.

b. **Surface Runoff from Storms Exceeding Design Storm.** Surface runoff from storms more severe than the design storm will be disposed of with minimum damage to the airfield or heliport. The primary runway or helipad must remain operational under all conditions.

c. **Reliability of Operation.** The drainage system will have the maximum reliability of operation practicable under all conditions, with due consideration given to abnormal requirements during annual periods of snowmelt and ice jam breakup.

d. **Maintenance.** The drainage system will require minimum maintenance, which will be accomplished quickly and economically. Particular reliance will be placed on maintenance of drainage components serving operational facilities.

e. **Future Expansion.** Future expansion of drainage facilities will be feasible with the minimum of expense and interruptions to normal traffic.

1-4. DEGREE OF DRAINAGE REQUIRED. The degree of protection to be provided by the drainage system depends largely on the importance of the facility, as determined by the type and volume of traffic to be accommodated, the necessity for uninterrupted service, and similar factors. Although the degree of protection should increase with the importance of the airfield or heliport, minimum requirements must be adequate to avoid hazards in operation. One severe accident chargeable to inadequate drainage can offset any difference between the cost of reasonably adequate and inadequate facilities. Drainage for military airfields or heliports will be based on a 2-year design storm frequency, unless exceptional circumstances require greater protection. For design purposes, a minimum supply rate of 0.2 inch per hour of rainfall plus snowmelt is to be used, even where intensity frequency studies for the Arctic indicate somewhat lower values. In mountainous areas subject to orographic precipitation, maps showing local variations of the design storm index will prove useful for drainage designs, provided that adequate long-term precipitation records are available to warrant such refinements. In some cases one can justify use of design storm frequencies appreciably higher than the 2-year rate to protect important facilities. In some U.S. designs, portions of the drainage

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system have been based on as high as a 50-year design frequency to reduce the likelihood of flooding a facility essential to operations and to prevent loss of life. Many designers find that using the 2-year design with this Corps of Engineers method will usually yield results comparable with use of a 10-year design based on the Rational Method.

SECTION 2. HYDROLOGIC CRITERIA

2-1. GENERAL. The Rational Method, developed over 100 years ago, is widely used for estimating design runoff from urban areas. The Rational Formula, popular because of its simplicity in application, is described in TM 5-820-4[7 28 36]. It is suited mainly to sizing culverts, storm drains or channels to accommodate drainage from small areas, generally less than 50 acres. Selection of appropriate values of runoff coefficients in the formula depends on the experience of the designer and his knowledge of local rainfall-runoff relationships. Use of the Rational Formula in the design of military airfield drainage systems, with their large, generally level contributory drainage areas, is not recommended. The development of hydrologic criteria in this report closely follows the procedure outlined in TM 5-820-1[4 37]. Part I of reference 22 is one of several confirming that this procedure accurately determines required hydraulic capacity of airfield drainage facilities with lessened dependence on arbitrary assumption of design factors. Although judgment is important in any engineering design, guesswork is minimized in use of this procedure which is based on theoretical concepts which have been verified in carefully controlled natural and simulated rainfall and runoff tests under widely varying hydrologic and topographic conditions. In the design of drainage facilities for the Arctic and Subarctic, additional capacity must, in many cases, be provided to compensate for that lost due to icings. This is discussed in Section 3, Icings.

2-2. RAINFALL. A study of rainfall intensity-frequency data recorded at arctic and subarctic stations indicates significant variance between the average intensity of rainfall for a period of 1 hour and the average precipitation rates of comparable frequency for shorter intervals. This is also evident when compared with similar rainfall data in the continental United States. Even within the area of Alaska, there is noticeable difference between the orographic rains of Juneau and the convergent and convective precipitation at Fairbanks. The higher values for rainfall intensity

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were used to develop design intensity-duration (supply) curves. Similar curves for the continental United States are shown in TM 5-820-1[4].

a. Design Storm Frequency. Design storm frequencies are normally stated in engineering instructions for the specific project. For airfields and heliports, the 2-year design storm frequency is most often used. It should be noted that after this design storm frequency is specified, computations must be made to determine the critical duration of rainfall required to produce the maximum rate of runoff for each area. This will depend primarily on the slope and length of overland flow.

b. Storms of Greater Severity than Design Storm. The design storm frequency alone is not a reliable criterion of the adequacy of storm drain facilities. Under some circumstances, storms much more severe than the design storm may cause very little damage or inconvenience, whereas under other circumstances flooding of important areas may result. It is advisable to investigate the probable consequences of storms more severe and less frequent than the design storm before making final decisions regarding the adequency of proposed drain-inlet capacities. Additional requirements necessitated by the effects of icings on drainage facilities in arctic and subarctic regions are discussed in Section 3.

c. Design Storm Index. One-hour rainfall intensities having various average frequencies of occurrence in the arctic and subarctic regions of Alaska and Canada are shown in Figure 2-1. This figure is known as a design storm index and is based on reports by the U.S. National Weather Service[29] and the Canadian Department of Transport, Meteorological Branch.[34] The curves are labeled according to the 1-hour amounts of rainfall and are coordinated with the supply curves of Figure 2-2. Figures 2-1 and 2-2 used in combination provide a sufficiently accurate means of determining rainfall intensities for runoff computations for any duration and geographic location.[21] Where data are incomplete for a specific foreign area under study, a generalized method for estimating the 2-year 1-hour value has been developed using usually available climatic data. This method uses a diagram (Fig. 3 of TM 5-820-1[4]) which relates the 2-year 1-hour rainfall to the following more commonly known climatic data: mean annual precipitation[35], mean annual number of days of precipitation, mean annual thunderstorm days, and mean of the annual maximum observational-day rainfall amounts. The diagram gives maximum 60-minute, not clock-hour, rainfall for the 2-year frequency.

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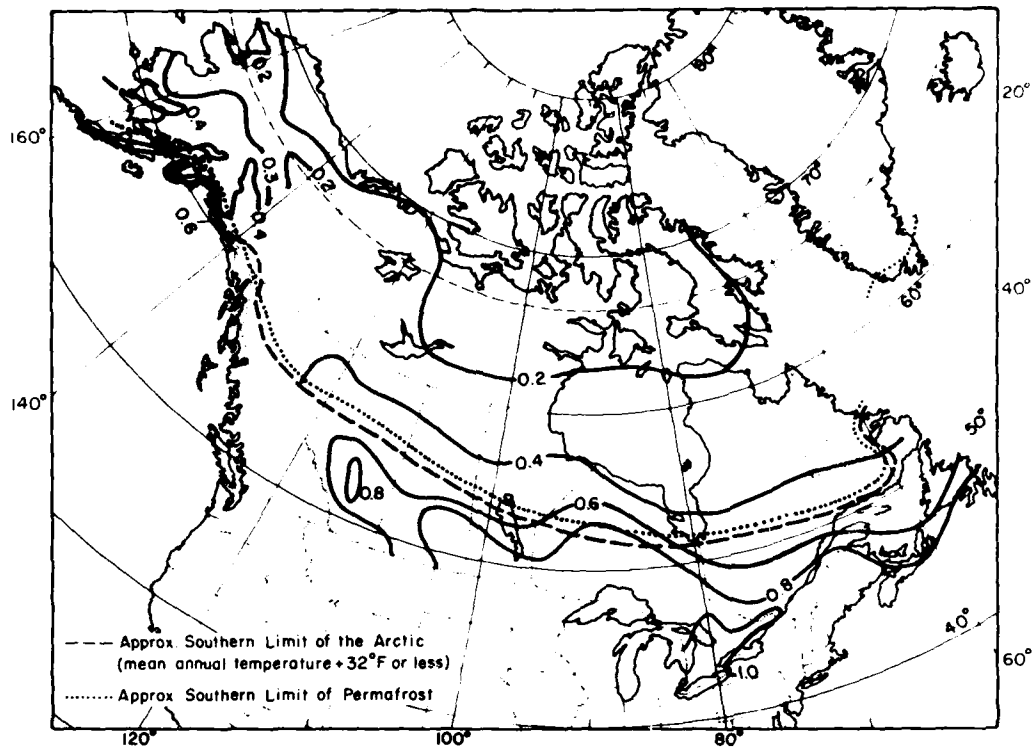
a. Once in 2 years.

Figure 2-1. Design storm index for Alaska and Canada: isolines of
maximum 1-hour rainfall (inches) occurring once in 2, 5, 10 and 25
years. Lines correspond to the intensity-duration curves in Figure
2-2. Data from U.S. National Weather Service,[29] the Canadian Dept.
of Transport, Meteorological Branch,[34] and Quartermaster Research
and Development Center.[39]
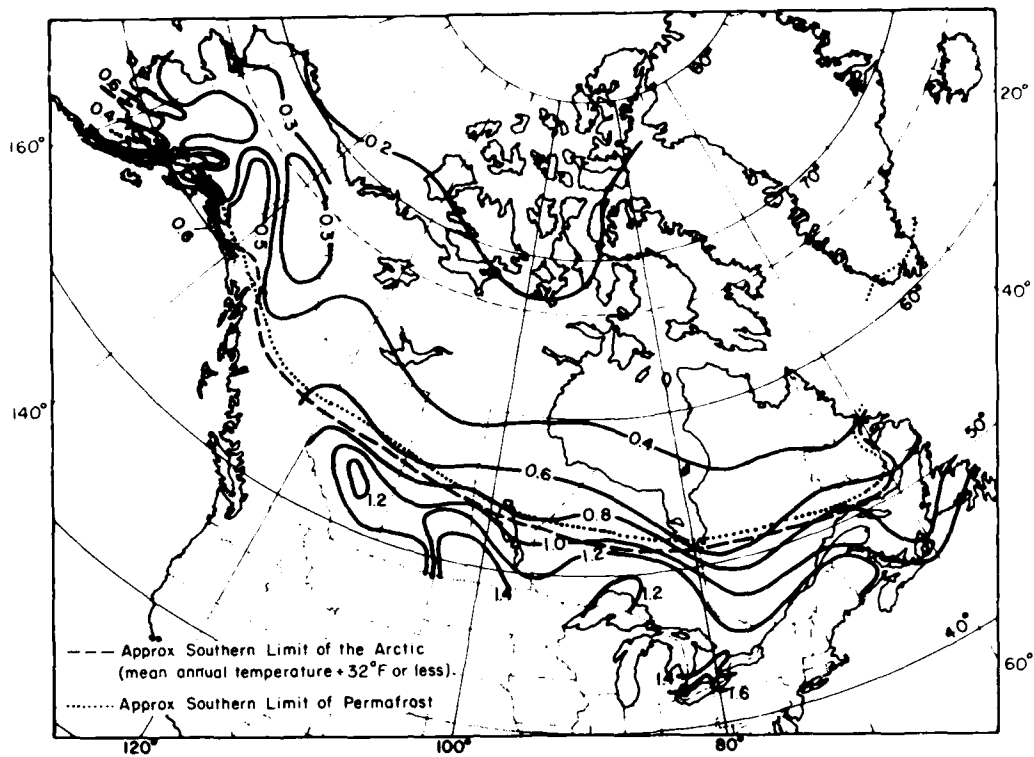
b. Once in 5 years.
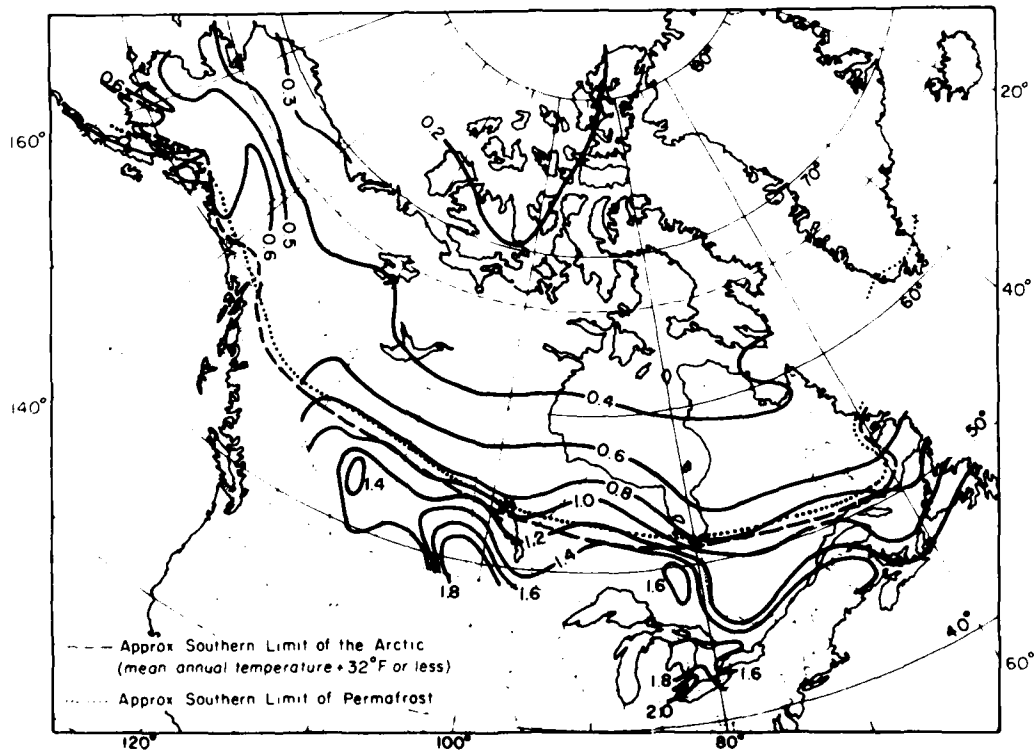
c. Once in 10 years.

Figure 2-1 (cont'd)

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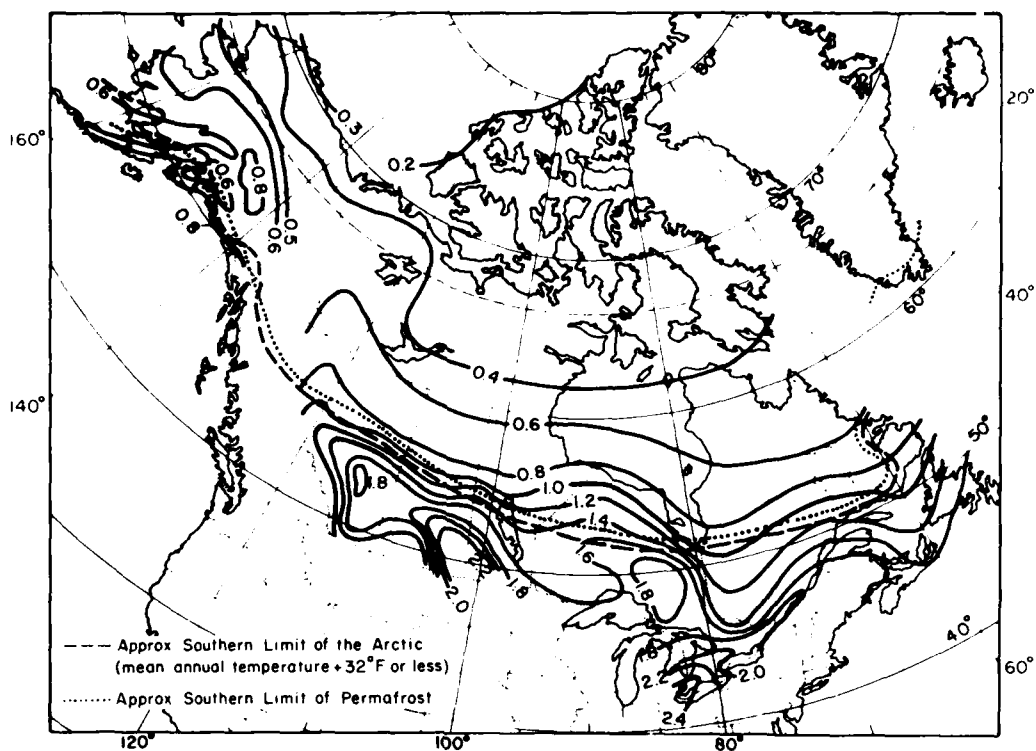
d.   Once in 25 years.

Figure 2-1 (cont'd)
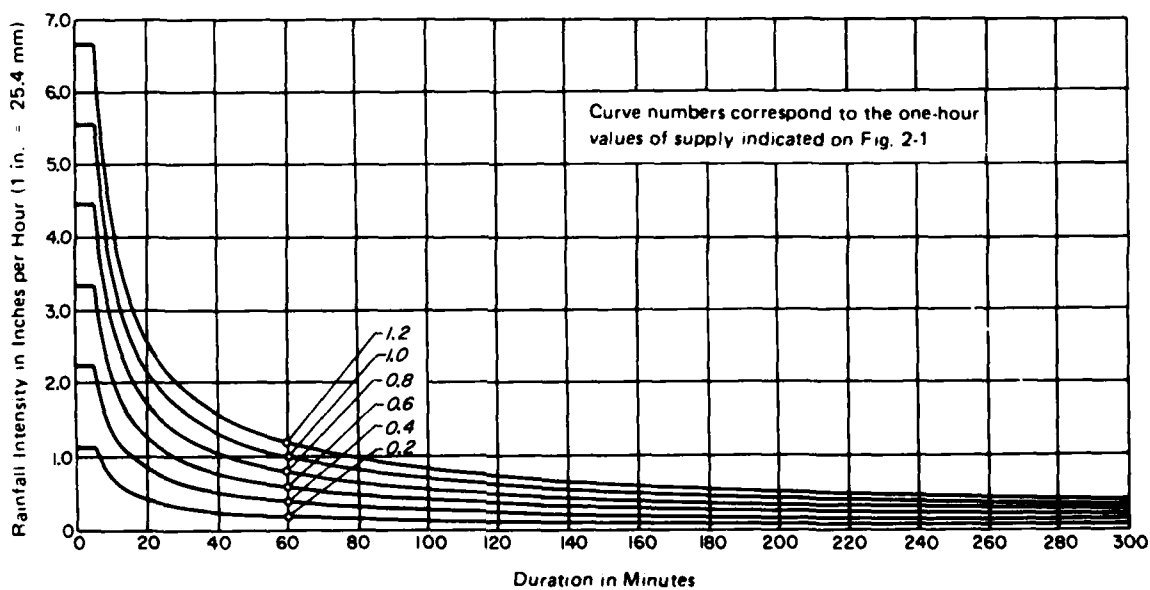
Figure 2-2.   Supply curves for arctic and subarctic regions.

2-3. INFILTRATION

a. Definition. As used here, the term "infiltration" refers to the absorption of rainfall by the ground during a design storm. The infiltration capacity, or ability of a soil to absorb precipitation, normally decreases as the duration of rainfall increases, until a fairly definite minimum rate is reached. Variations in the degree of compaction, soil moisture deficiencies at the beginning of rainfall, and the depth to the groundwater table may greatly influence the infiltration capacity of a particular soil.

b. Variability. Because of several variables that affect the infiltration capacity of a given soil, it is impracticable to determine accurately the infiltration capacities assumed to apply during storms. The rate of infiltration changes not only during the course of a storm but also during a season. The infiltration rate also varies with the type of soil structure, the soil cover, the temperature of air, soil, and water, the moisture content of soil, turbidity of the water, and the amount of organic matter in the soil. The total porosity of a soil determines to a considerable extent the total amount of water that may filter into it. Available data indicate that the rate of infiltration increases with a rise in the temperature of the air, soil and water, and conversely, the rate of infiltration lessens with an increase in the moisture content of the soil. Soils with a high organic matter content also have high infiltration rates. Vegetation cover serves as a protection from the impact of rain, retards the rate of runoff, and thereby reduces the velocity of overland flow and turbidity, and permits greater infiltration of water into the soil. Rates of infiltration on bare soil can be expected to be considerably less than those for turfed areas. For use in the design of storm drains for a particular airfield or heliport, the infiltration capacity that is estimated to be characteristic of the given soil, following a rainfall of 1 hour, serves as the most convenient index to the probable volume of loss through infiltration during the design storm. Antecedent rainfall conditions such as those ordinarily occurring during seasons in which the adopted design storm is likely to occur will be assumed in estimating the 1-hour infiltration rate referred to above.

c. Rate. In permafrost regions, groundwater percolation rates are much lower than in thawed soils and the rate of infiltration for design purposes should be considered zero. In other areas, a good guide can be

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obtained when test borings are made. Rates would normally not exceed about 0.5 inch per hour for clayey soils with low permeability.

2-4. SNOWMELT. Airfields, heliports and other pavement areas in the Arctic and Subarctic are subjected to their most critical drainage requirements during spring thaw and other periods of snow and ice melting. Initial periods of higher temperatures and longer days result in densification or "ripening" of snow, and subsequently, snowmelt runoff. With banked water-laden snow on or adjacent to pavements, inlets and drainage ditches, a maximum rate of runoff from snowmelt, exclusive of rainfall, is about 0.1 inch (0.3 cm) per hour. In regions of lesser snowfall accumulation, snowmelt runoff at half this rate, 0.05 inch (0.15 cm) per hour, would be expected. Accordingly, an amount of 0.05 to 0.1 inch per hour for snowmelt will be added to the design rainfall intensity rate for drainage facilities in the Arctic and Subarctic.

2-5. SUPPLY. The term "rate of supply" refers to the rainfall intensity plus snowmelt minus the infiltration capacity at the same instant of a particular storm. To simplify computation procedures, the rainfall intensity, rate of snowmelt and infiltration capacity are assumed to be constant during any specific storm. On this premise, the rate of supply during a particular storm would also be uniform.

    a. Average Rates of Supply. Average rates of supply corresponding to storms of different durations and the same average frequency of occurrence can be computed by subtracting estimated infiltration capacities from rainfall plus snowmelt intensities represented by the proper standard rainfall intensity-duration curve in Figure 2-2. For convenience, standard supply curves are assumed to have the same shape as the rainfall intensity-duration curves. For example, if curve 0.8 in Figure 2-2 was indicated by Figure 2-1 as the design rainfall plus snowmelt, and infiltration loss at the rate of 0.2 inch per hour was estimated to be applicable, curve 0.6 would be adopted as the supply curve for that area.

    b. Weighted Standard Supply Curves. In most cases, drainage areas consist of combinations of paved and unpaved areas having different infiltration capacities. To simplify computations, weighted standard supply curves should be estimated for composite tributary drainage areas by weighting the standard supply curve numbers adopted for paved and unpaved surfaces in proportion to their respective areas.

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2-6. RUNOFF

   a. Notation. Symbols used in equations and discussions contained in
the following paragraphs are defined below:

   L = effective length of overland flow, in ft. (See discussion of
        effective length in subparagraphs c. and e. below.)

   n = retardance coefficient.

   Q = discharge capacity, in ft^3/sec at a designated point.

   Q_d = drain-inlet capacity, in ft^3/sec.

   q = rate of overland flow at the lower end of an elemental strip of
        turfed, bare, frozen or paved surface, in in./hr or in ft^3/sec per
        acre of drainage area.

   q_d = drain-inlet capacity, or maximum rate of outflow from a ponding
        area, in ft^3/sec per acre of tributary drainage area.

   q_p = peak runoff rate, in in./hr or ft^3/sec per acre of drainage
        area.

   S = slope of surface, or hydraulic gradient.

   t = time, or duration, in minutes; time from beginning of supply.

   t_c = critical duration of supply, in minutes; that is, the duration
        of rainfall plus snowmelt excess (rate of supply) for a given
        standard supply curve that would produce the maximum rate of out-
        flow from a given drainage area, taking into account surface
        detention and surface runoff characteristics.

   t_d = time required for water to travel from a specified inlet to a
        given point in the drainage system, in minutes.

   t_r = duration of supply, in minutes.

   σ = rate of supply or rainfall plus snowmelt in excess of the rate of
        infiltration, in in./hr.

 tanh = hyperbolic tangent (defined as the quotient of the hyperbolic sine
        divided by the hyperbolic cosine, i.e.,
        tanh x = sinh x/cosh x, the hyperbolic functions of having the
        same relationship to the equilateral hyperbola as the trigono-
        metric functions do to the circle).

   b. Overland Flow Equation. The term "overland flow" as used here
relates to surface runoff, resembling sheet flow, before it has reached a
defined channel or ponding basin. Horton[38] developed an equation for the
rate of overland flow to be expected from a uniform rate of rainfall

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excess, or rate of supply, which in a form modified for this report is as follows:

$$q = \sigma \tanh^2[0.922t\ (\sigma/nL)^{0.50}S^{0.25}]$$

c. Effective Length. In the basic derivation of the above equation, the term L, effective length, represents the length of overland sheet flow measured in a direction parallel to the maximum slope, before the runoff has reached a defined channel. In actuality, particularly in large drainage areas and under many conditions of grading, considerable channelized flow will occur during the design storm conditions. Investigation of many runoff records for watersheds similar to typical airfield and heliport areas in the continental United States indicates that by modifying the determination of effective length, satisfactory reproduction of runoff by hydrographs can be obtained regardless of channelization of flow. The effective length L is the sum of the channelized flow length and the overland flow length, each converted to an equivalent length for n = 0.40 and S = 1.0% by means of Figure 2-3. The length of channel flow is measured along the proposed collecting channel or swale for that section in which appreciable depth of flow may occur during the design storm. Length of overland flow is the average distance from the end of the effective channel, if any, or the drain to the outer periphery of the drainage area. Even with excellent grading, overland flow lengths seldom exceed a few hundred feet before channelization occurs. Typical values of the retardance coefficient n for use in determining equivalent length of overland flow are shown in Table 2-1. A guide to selection of n values in the case of channelized flow is shown in Figure 2-4. A more detailed description of the procedure for selecting "n" values is contained in TM 5-820-1[4] and TM 5-820-3[5].

d. Ponding. Although provision of ponding areas is advantageous in temperate zone drainage designs, ponding on or alongside paved areas should be avoided in permafrost regions. There, water accumulated alongside airfield or roadway pavement embankments can cause thermal as well as mechanical erosion. Saturation of fine-grained soil and subsoil shortly before freezeup in the fall may greatly increase subsequent frost heaving damage.

e. Effect of Paved Area on Determination of Effective Length. The time required for water to run off the average paved or ice-covered area is

L" or Length-value in Feet Required to Obtain Correct Discharge by Use of Overland Flow Curves Computed for S = 1%

B. Correction for Differences in Slope (S)

S = 0.5%   0.3%   0.2%   0.1%
0.7%
1.0%
1.5%
2%
3%
5%
10%
20%
50%

Actual or Effective Length of Strip Having the Surface Slope "S" Indicated by Parameter or L' if Correction in Retardance Coefficient factor is Necessary

L' or Length-value in Feet Required to Obtain Correct Discharge by Use of Overland Flow Curves Computed for n = 0.40

Actual or Effective Length of Strip Having the Retardance Coefficient "n" Indicated by Parameter

A. Correction for Differences in Retardance Coefficient (n)

n = 0.01 (SMOOTH PAVEMENTS)
n = 0.06
n = 0.10 (BARE PACKED SOIL FREE OF STONE)
n = 0.15
n = 0.20 (SPARSE GRASS, OR ROUGH BARE SURFACE)
n = 0.40 (AVERAGE GRASS COVER)
n = 0.50
n = 0.60
n = 0.80 (DENSE GRASS COVER)

Figure 2-3. Airfield drainage-overland flow relations. Modification in L required to compensate for differences in n and S.

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Table 2-1.   Retardance Coefficients for Overland Flow.

Surface	Value of n
Pavements and frozen ground	0.01
Bare packed soil free of stone	0.10
Sparse grass cover, tundra or moderately rough bare surface	0.20
Average grass cover	0.40
Dense grass cover	0.80
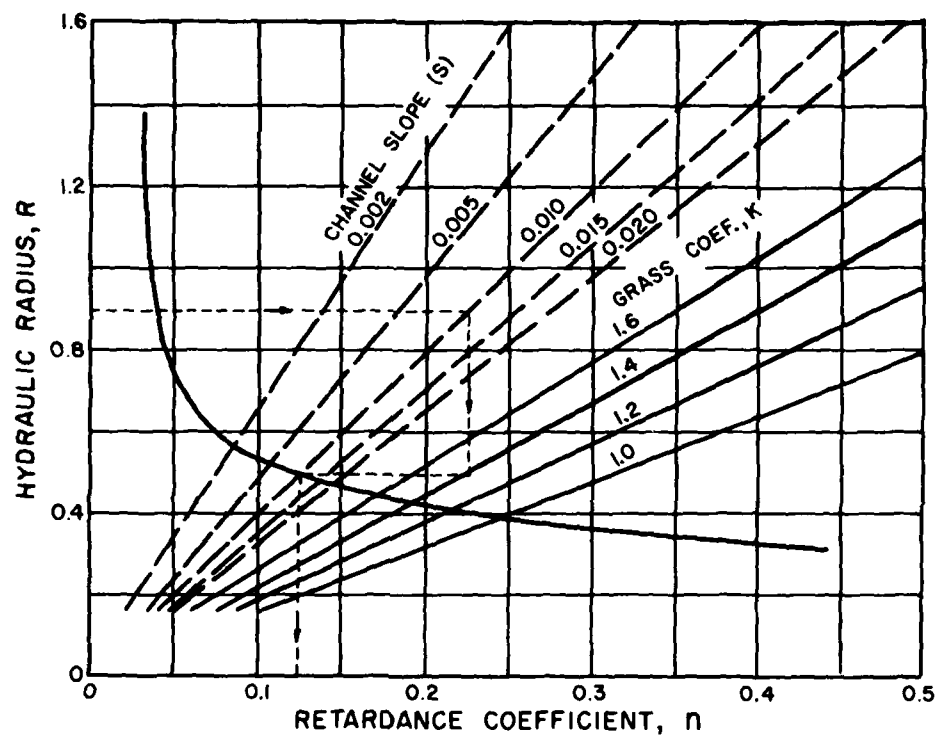
AVERAGE GRASS COEFFICIENT (K) FOR DENSE AIRFIELD TURF

AVERAGE LENGTH OF GRASS IN INCHES	Under 6 in. (0-15 cm)	6 to 12 in. (15-30 cm)	Over 12 in. (30 cm)
GRASS COEF. (K)	1.4	1.3	1.2

EXAMPLE:

   Determine "n" for a channel with 4 inches of dense grass, R = 0.9, and S = 0.010.

   From table, K = 1.4; from graph, by following dotted line, "n" is equal to 0.12.

Figure 2-4.   Retardance coefficients for flow in turfed channels.

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normally very short. Consequently, the length of the paved area need be given little weight in estimating the effective length L for a composite area. As q is inversely proportional to L, it is helpful to grade the slopes so that the drain inlet is located as far as practicable from the watershed center. In a rectangular area, a drain inlet located near a corner would require less discharge capacity than one located in or near the center of the plot.

f. Relation of Overland Flow to Standard Supply Curves. The curves shown in Figures 2-5 through 2-10 were obtained by computing the rates of discharge, at appropriate time intervals, that would result from various rates of supply, corresponding to the respective standard supply curves of Figure 2-2. The procedure is illustrated by the sample computations in Table 2-2. The curves shown are not hydrographs for any specific design storm but represent the peak rates of runoff from individual storm events of various durations, all of which have the same average frequency of

Table 2-2

Rates of overland flow corresponding to intensities shown on supply curve 0.2 in Figure 2-2.

Duration of supply, min.	Rate of supply, in./hr.	Rate of overland flow in c.f.s. for various durations and rates of supply where L equals										
		20 ft.	40 ft.	60 ft.	80 ft.	100 ft.	150 ft.	200 ft.	300 ft.	400 ft.	600 ft.	800 ft.
3	1.113	0.111	0.058	0.039	0.031	0.024	0.017	0.013	0.009	0.008	0.006	0.003
5	1.113	.273	.149	.104	.080	.065	.043	.035	.023	.018	.011	.009
7	0.883	.306	.175	.122	.093	.077	.053	.041	.027	.022	.015	.011
9	.743	.328	.194	.137	.107	.087	.060	.046	.031	.025	.016	.013
12	.608	.340	.213	.154	.122	.100	.069	.053	.036	.028	.019	.015
15	.522	.339	.227	.167	.133	.110	.078	.060	.041	.031	.022	.017
20	.430	.329	.237	.184	.148	.125	.090	.069	.048	.037	.030	.020
25	.367	.308	.236	.190	.157	.132	.097	.076	.054	.041	.029	.023
30	.323	.287	.232	.191	.162	.139	.103	.081	.058	.045	.031	.024
35	.292	.269	.226	.192	.164	.145	.109	.088	.063	.049	.034	.026
40	.265	.250	.217	.188	.164	.145	.112	.091	.065	.052	.036	.028
45	.245	.235	.210	.184	.164	.147	.115	.094	.069	.054	.038	.030
50	.227	.220	.201	.179	.161	.145	.116	.096	.071	.056	.040	.031
60	.200	.197	.184	.170	.155	.143	.117	.100	.075	.060	.043	.034
80	.163	.162	.157	.149	.141	.133	.115	.100	.079	.065	.048	.038
100	.140	--	.138	.134	.129	.123	.110	.099	.081	.068	.051	.041
120	.123	--	--	.120	.117	.113	.104	.095	.080	.069	.054	.043

Top chart (Figure 2-6)

SUPPLY CURVE NO. 0.4

RATES OF OVERLAND FLOW CORRESPONDING TO STANDARD SUPPLY CURVES

n=0.40   s=1%

n=0.40

FOR NOTATIONS SEE FIGURE 2-5

MAXIMUM RATE OF RUNOFF IN INCHES PER HOUR OR C.F.S. PER ACRE

1.8 1.6 1.4 1.2 1.0 0.8 0.6 0.4 0.2 0

DURATION OF SUPPLY IN MINUTES

0 20 40 60 80 100 120

σ t_c

L=20 L=40 L=60 L=80 L=100 L=150 L=200 L=300 L=400 L=600 L=800 L=1000

Figure 2-6. Supply curve No. 0.4

Bottom chart (Figure 2-5)

SUPPLY CURVE NO. 0.2

RATES OF OVERLAND FLOW CORRESPONDING TO STANDARD SUPPLY CURVES

n=0.40   s=1%

n=0.40

SYMBOLS SHOWN IN FIGURES 2-5 THROUGH 2-10

L = effective length in feet (1 ft - 0.3 m)

σ = rate of supply in inches depth per hours
(1 in. = 2.54 cm)

t_c = critical time of runoff in minutes, assuming surface storage as negligible.

EXAMPLE: L=40 ft, t_c =23 min.
q_d = 0.24 in/hr. or cfs/acre

MAXIMUM RATE OF RUNOFF IN INCHES PER HOUR OR C.F.S. PER ACRE

0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0

DURATION OF SUPPLY IN MINUTES

0 20 40 60 80 100 120

σ t_c

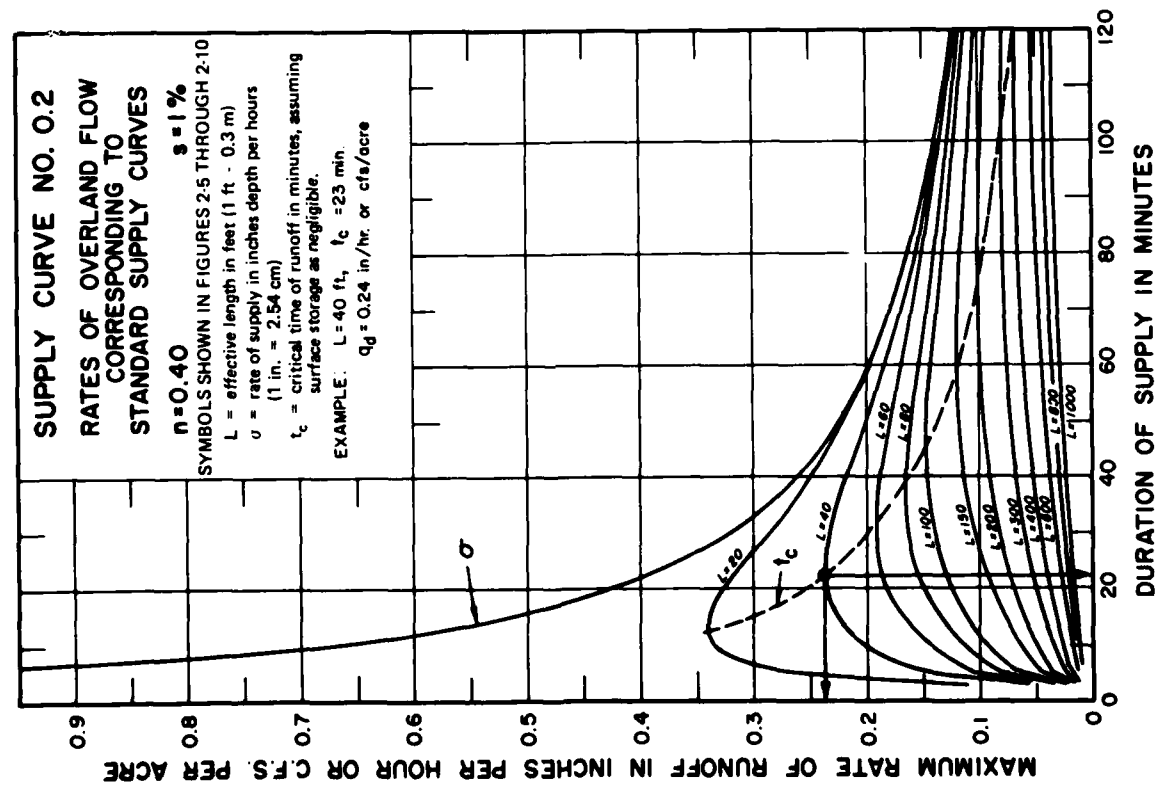L=20 L=40 L=60 L=80 L=100 L=150 L=200 L=300 L=400 L=600 L=800 L=1000
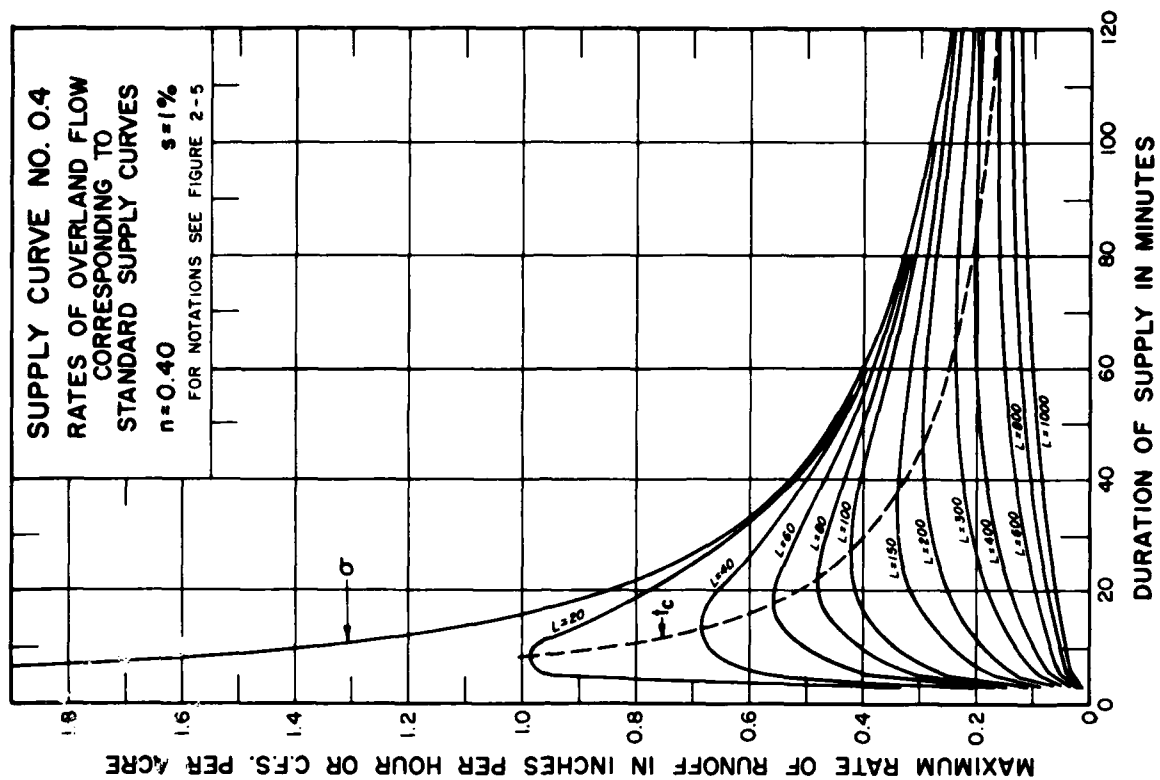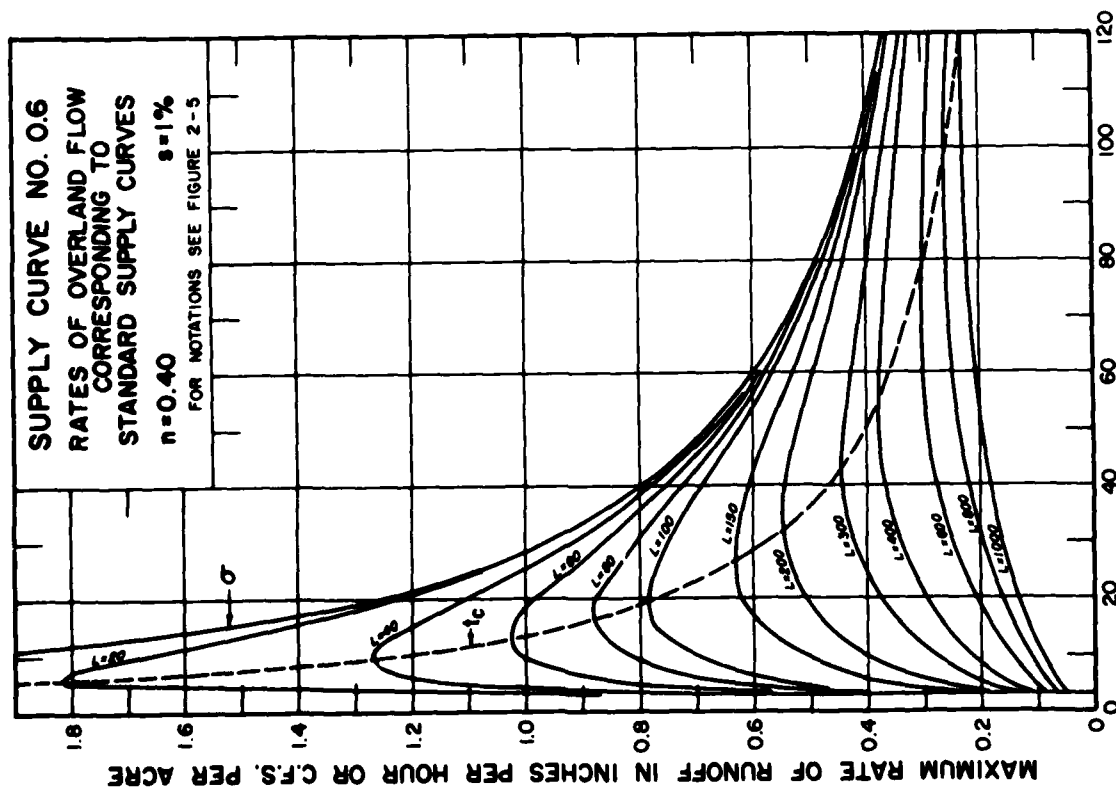
Figure 2-5. Supply curve No. 0.2

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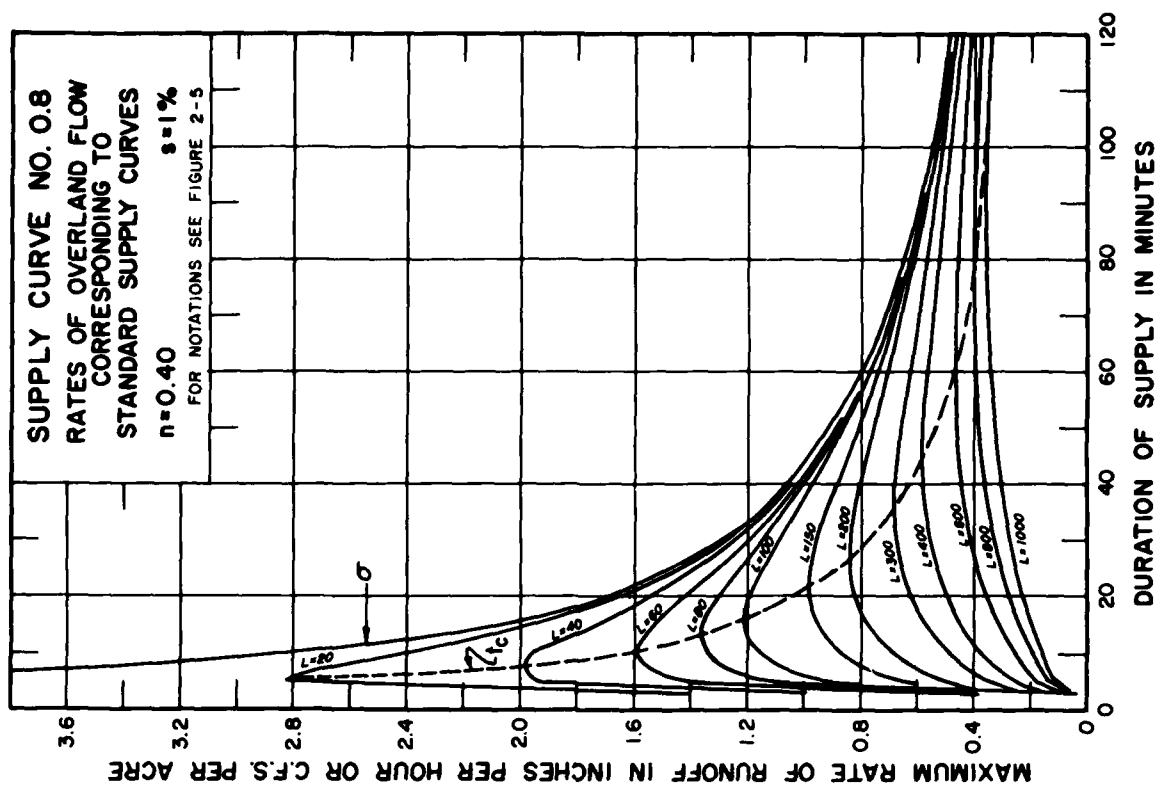Figure 2-8. Supply curve No. 0.8.
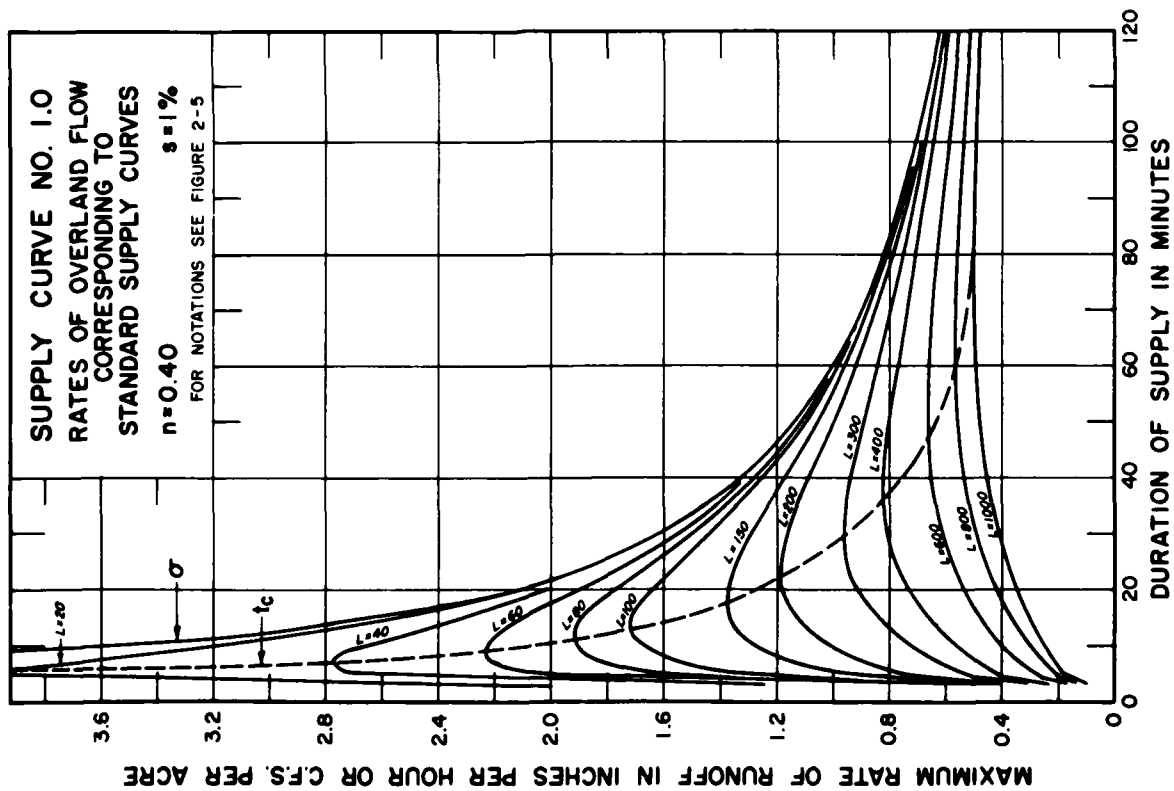

Figure 2-7. Supply curve No. 0.6

16

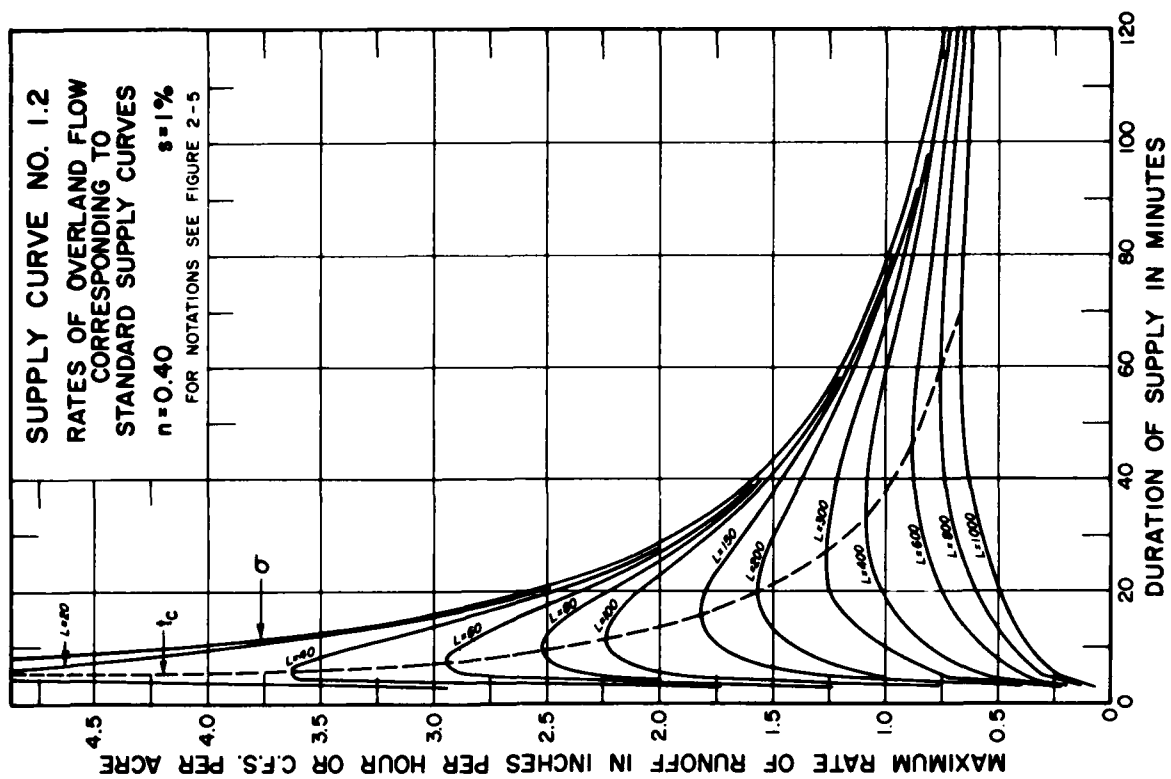Figure 2-10. Supply curve No. 1.2.

Figure 2-9. Supply curve No. 1.0.

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occurrence. The duration of supply corresponding to the greatest discharge
for a particular standard supply curve and value of L in Figures 2-5
through 2-10 is defined as the critical duration of supply t_c for runoff
from an area.

SECTION 3. ICINGS[17] [19]

3-1. DESCRIPTION. The term icing (sometimes misnamed "glaciering")
applies to a surface ice mass formed by the freezing of successive sheets
of water, the source of which may be a river or stream, a spring, or
seepage from the ground. When icings occur at or near airfields, heli-
ports, roadways or railroads, the drainage structures and channels
gradually fill with ice, which may spread over pavements or structures,
endangering and disrupting traffic and operations. Ice must be removed
from pavements or structures, and drainage facilities must be cleared to
avoid or limit the re-forming of icings. Obstruction of flow through
drainage facilities - culverts, bridges, pipelines or channels - can lead
to washout of pavement embankments or undermining of structures. The
spring thaw period at or near drainage structures and the related effects
on pavements and other facilities is a key objective of drainage design and
maintenance in the Arctic and Subarctic. As icings can occur throughout
both seasonal frost and permafrost areas, they are a widespread cause of
recurring operational and maintenance problems. Drainage designs based
only on conventional criteria will not fulfill the abnormal hydraulic con-
veyance requirements of icing-prone regions and will be subject to trouble-
some maintenance problems. Special design and maintenance concepts, based
mainly on field experienc' under similar situations, are required.

3-2. TYPES.[18] Icings ar classed conveniently as river or stream icings,
ground icings, or spring icings, although sometimes it is difficult to
assign a specific type to a particular situation. The three general types
of icings are discussed below.

　　a. River or Stream Icings. These occur more commonly on shallow
streams with large width/depth ratios. Braided or meandering channels are
more prone to icing formation than well defined single channels. River or
stream icings normally begin to develop soon after normal ice cover forms
on a stream surface, generally during October to December. The icing
begins with the appearance of unfrozen water on the surface of the normal
ice cover. This water may originate from cracks in the ice cover, from
seepage through unfrozen portions of soil forming the channel banks, from

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adjacent springs which normally discharge into the channel, or other sources. This water, flowing in sheets an inch or less in thickness to a foot or more, freezes in a layer. Each overflow event is followed by another, with new flow atop the previously frozen sheet, the icing growing higher layer upon layer, with its boundaries extending laterally according to the topography. River icings may grow for only part of the winter or throughout the period of below-freezing temperatures. Icing behavior usually varies but little year by year, depending on availability of the feeding water. An icing surface is generally flat but can be gently terraced, with each step marking the frozen edge of a thin overflow layer. Occasionally ice mounds form, and cracks develop, providing outlets for the confined water forming the mounds. The water flows out, continuing the growth of the icing for a limited period.

Smaller icings are generally confined to the stream or drainage channel; larger ones may spread over floodplains or pavements. With onset of the spring thawing season, runoff cuts channels through the icing to the streambed. Channels are widened by thawing, collapse of the ice forming the sides, and erosion. Depending on the size of the icing and its geographic location, its remnants may last only until May or June, or in colder regions it may last all summer. In extreme climates, they never completely melt and are known as perennial icings. River or stream icings occurring at culverts are also objectionable in that they obstruct fish migration.

b. Ground Icings. Unlike river or stream icings, ground icings, while developing on certain topographic features, do not have clearly defined areas of activity. They are commonly referred to as seepage icings, because of the way their feed waters appear on the ground surface. They may develop on nearly level ground or at points of contact of two different types of relief (such as at the base of a slope) or as encrustations on slopes. Ground icings begin to form at different times of the year, depending on the sources and modes of discharge of the feeding waters. Where water seeps from the ground often or continuously, icings may begin to form in September or October, in which case they might also be termed spring icings. Those forming where water does not usually issue from the ground generally begin to form in November or December or even later in the winter. A characteristic of ground icings is that their development begins with unfrozen water appearing on the ground surface or with the saturation and subsequent freezing of snow on the ground. This

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water may seep from the soil or fractures in the bedrock, it may travel along the roots of vegetation, or it may issue from frost-induced cracks in the ground. As the seepage flows are exposed to the cold atmosphere, they freeze, to be followed repeatedly by additional seepages onto the icing surface that also freeze, building up successive thin ice layers, seldom over an inch thick. Ground icings may grow during the winter, being extremely sensitive to weather and local hydrologic conditions of the winter and its preceding seasons. Normally ground icings are limited in size compared with stream or spring icings since their source of supply is limited. Some rapid growth may occur with advent of thawing weather, if the icing is situated to collect water from snowmelt during the day, with freezing occurring at night. When general thawing occurs, the ground icing will slowly waste away. This disintegration is unlike that of stream icings, where sizeable runoff streams can rapidly erode icings.

c. Spring Icings. Springs found in a variety of topographic situations sustain continuous discharge, leading to early winter formation of icings, generally prior to ground icings. Spring icings continue to grow throughout the winter, ultimately reaching a larger size than ground icings. A flow of 1 ft^3/min can create a 1-ft-deep icing covering an acre in one month. Spring icings melt away slowly on all sides and are also eroded by spring water channel flow.

3-3. NATURAL FACTORS CONDUCIVE TO ICING FORMATION. These can be summarized as follows:

a. A rainy season prior to freeze-up, producing an abundance of groundwater in the annual frost zone of the soil or in the ground above the permafrost.

b. Low air temperatures and little snow during the first half of the winter, that is through January. Early heavy snow minimizes occurrence of icings.

c. Nearness of an impervious horizon such as the permafrost table to the ground surface.

d. Heavy snow accumulations during the latter part of winter.

3-4. EFFECTS OF MAN'S ACTIVITIES ON ICINGS. Airfields and heliports, by altering the natural physical environment, have profound effects on icings. The widespread clearing of vegetative cover, cutting and filling of soil, excavation of rock, and provisions for drainage, for example, greatly affect the natural thermal regime of the ground and the hydrologic regimes

of both groundwater and surface water. Some of these effects are discussed below.

a. Removal of vegetation and organic soil, which generally have higher insulation values than the construction materials replacing them, results in increased seasonal frost penetration. This may create or aggravate nearby damming of groundwater flow and cause icings. Airfield and heliport pavement areas, kept clear of snow, lack its insulating value and are subject to deeper seasonal frost penetration, causing icings.

b. Cut faces may intersect the water table, and fill sections may block natural drainage channels. Construction compaction operations can reduce permeability of natural soils, blocking natural discharge openings.

c. In cut sections, water comes into contact with the cold atmosphere, forming ground icings where none occurred prior to the construction. Icings grow on the cut face, fill the adjacent drainage ditches with ice, and eventually reach the pavement surface. In these conditions, deep snow on the slope and ditch insulates seepage from the cut face. Seepage water passes under the snow without freezing and reaches the snow-free pavement, where it is sufficiently exposed to freeze. This type of man-made icing is the most common and troublesome type along pavements.

d. Snowplowing and storage of snow greatly affect the location and extent of icings by changing insulation values and damming seepage waters.

e. Channel realignment and grading into wider, more shallow sections, commonly done in airfield and heliport construction, renders the stream more susceptible to high heat losses and extensive freezing and formation of icings.

f. Drainage designers customarily size hydraulic structures to accommodate runoff from a specified design storm. In the Arctic and Subarctic, the size of hydraulic structures based solely on these well-founded hydrologic principles will usually result in inadequate capacity, which will contribute or intensify icing formation. Culverts, small bridges, storm drains and inlets designed to accommodate peak design discharges are generally much too small to accommodate icing volumes before becoming completely blocked by ice. Once the drainage openings become blocked, icings upstream from the affected structures will grow markedly. The inadequacy of drainage facilities, both in capacity and number, because of failure to accommodate icings, leads to more serious effects of icings on engineering works.

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3-5. METHODS OF COUNTERACTING ICINGS. Several techniques are available for avoiding, controlling, or preventing icings. Although sound in principle, the methods are often applied without adequate understanding of the icing problems encountered, leading to unsuccessful or poor results. Selection of a particular method from the many that might be applied for the given set of conditions is based principally on economics. One must use a systems approach considering costs of installation plus costs of operation and maintenance, energy conservation, and environmental impact. Where feasible, methods requiring no fuel or electrical energy output or little or no service by maintenance personnel are preferred. The techniques for dealing with icings fall into two categories: avoidance and control and prevention. These are discussed below.

a. Methods of Icing Avoidance and Control. These deal with the effects of the icings at the location being protected, so that the type of icing (river or stream, ground, or spring) is of little significance. Methods are as follows:

(1) Change of location. Site facilities[11] where icings do not occur. This is an economic consideration difficult to resolve in siting an airfield with its extensive area, grading, and lateral clearance requirements.

(2) Raising grade. This will deter or postpone icing formation but is costly and depends on availability of ample fill. There is also threat of embankment washouts resulting from ice-blocked facilities, and possibility of objectionable seepage effects.

(3) More and larger drainage structures. Susceptibility to icing problems can be reduced by providing more and larger drainage facilities. Openings as much as 2 or 3 times as large as those required by conventional hydraulic design criteria will accommodate sizable icing volumes without encroaching on design flows. Culverts with large vertical dimensions, or small bridges in lieu of culverts, are advantageous. Provision for adequate drainage channels and conduits will facilitate diversion of meltwater runoff from icings, protecting the installation from washouts.

(4) Storage space. This can be provided as a ponding basin or by shifting a cut face further back from the airfield or heliport. There, an icing can grow in an area where it will not encroach on operational facilities.

(5) Dams, dikes or barriers. Known also as ice fences, these are often used to limit the horizontal extent of icings. Permanent barriers of

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earth, logs or lumber may be built between the source of the icing and the area to be protected. Temporary barriers may be erected of snow embankments, movable wooden fencing, corrugated metal, burlap, platic sheeting, or expedient lumber construction. In some situations, a second or even third fence is required above the first as the icing grows higher.

(6) Culvert closures. To prevent a culvert being filled with snow and ice, which requires a laborious spring clearing operation, closures are sometimes placed over the culvert ends in the fall. These can be of rocks to permit minor flows prior to freeze-up.

(7) Staggered (or stacked) culverts. This involves placement of two (or more) culverts, one at the usual location at the base of the fill, the other(s) higher in the fill. When the lower culvert becomes blocked by an icing accumulation, the higher ones carry initial spring runoff over the icing. As the spring thaw progresses, the lower one becomes cleared, eventually carrying the entire flow. In cases where there is limited height, the second culvert is placed to the side, with its invert at a slightly higher elevation. The ponding area available for icing accumulations must be large enough to store an entire winter's ice without having the icing reach the upper culverts or the elevation of the area being protected.

(8) Heat. Icings are commonly controlled by the application of heat in any of several ways, the objective being not to prevent icings but to establish and maintain thawed channels through them to minimize their growth and to pass spring runoff.

(9) Steam. This method, common in North America, is used to thaw culvert openings and to thaw channels into icings for collecting icing feed water or early spring runoff. Steam, generated in truck-mounted boilers, is conducted through hoses to portable steam lances. or through hoses temporarily attached to permanently installed thaw pipes supported inside the tops of the culverts. Thaw pipes of 3/8- to 2-inch (1- to 5-cm) diameter have been used. The thaw pipe is terminated by a vertical riser at each end of the culvert, extending high enough to permit access above accumulated ice and snow. The pipe is filled with antifreeze, with the risers capped when not in use.

(10) Fuel oil heaters. These heaters, known as firepots, are in common use. They consist of a 55-gallon (208-liter) oil drum, equipped with an oil burner unit (railroads often use coal or charcoal as fuel).

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The drum, fed from a nearby fuel supply, is usually suspended from a tripod at the upstream end of the culvert. A continuous fire maintains a thaw pit in the icing. Fuel consumption varies, averaging about 30 gallons (114 liters) per day. Water flows over the icing, enters the pit where it receives heat, and passes through the culvert, hopefully without refreezing before it flows beyond the area to be protected. While firepots are simple devices, they are inefficient energy sources due to loss of most heat to the atmosphere rather than to the water or icing. Firepots are in decreasing favor due to high maintenance requirements and difficulty in preventing theft of fuel in remote locations.

(11) Electrical heating.[20] Use of insulated heating cables to heat culverts is a recent adaptation successfully used where electrical power is available or, in important locations, where small generating stations would prove feasible. Heating cables have been used, not to prevent icing, but to create and maintain a thawed tunnel-like opening in an icing to minimize its growth and to provide for spring runoff. Cable can be strung in the fall within the culvert and, in some cases, along its upstream drainageway and removed in the spring. Cable can also be permanently installed in a small diameter metal pipe inside the culvert or buried at shallow depth under a drainage ditch or channel. Common heat output is 40 to 50 watts/lineal foot (131-164 W/m) with minimum heat loss to the atmosphere. A tunnel about 2-3 ft (0.6-0.9 m) wide and 4-5 ft (1.2-1.5 m) high is achieved by late winter. Electrical heating requires much less attention by maintenance personnel than steam thawing.

(12) Breaking and removing accumulated ice. This common technique, whether by manual or mechanical equipment, should be practiced only as an expedient or emergency measure. Timing of such operations, as for the following two methods, critically limits their effectiveness.

(13) Blasting. This has a twofold objective - physical removal of ice and fracturing ice to provide paths for water flow deep in the icing. This flow can enlarge openings and still remain protected from the atmosphere and refreezing.

(14) Deicing chemicals. Chemicals such as sodium or calcium chloride are sometimes used to prevent refreezing of a drainage facility, once it has been freed of ice by other means. A common practice is to place a burlap bag containing the salt at a culvert inlet, allowing the compound to

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be slowly dissolved by flow, the solution lowering the freezing point of the water. Objections are the detrimental effects on fish and wildlife, vegetation, and other downstream water uses and corrosive effects on metal pipe.

b. Methods of icing prevention. These preventive techniques are best classified according to the general type of icing (paragraph 3-2 above), as follows:

(1) River or stream icings.

(a) Channel modification. Straightening and deepening a channel can prevent icings, although frequent maintenance is usually required to counteract the stream's tendency to resume natural configuration by erosion and deposition. Rock-fill gabions have been used to create a deep, narrow channel for low winter discharges. Such deepened channels permit formation of ice cover to normal thickness while providing adequate space beneath for flow. Deepening at riffles, rapids, or drop structures is especially important as icings are most apt to form in these shallow areas.

(b) Insulation of critical sections. These icings may be prevented by insulating critical sections of the stream where high heat losses cause excessive thickening of the normal ice cover, to constrict or completely block flow and result in icing formation. These sections may be located under a bridge or taxiway or at riffles or rapids. The insulation which may be placed on the initial ice cover may consist of soil, snow, brush, peat, sawdust or other material, typically 1 to 2 ft (0.3 - 0.6 m) thick. Another way is to cover the stream before ice forms, using logs, timber, or corrugated metal as a support for insulating material later augmented by snowfall. Insulating covers, while beneficial in lessening heat losses from the stream, must be removed each spring before annual freshets.They may also be washed downstream to become obstructions if high water occurs prior to cover removal.

(c) Frost belts. Known also as "permafrost belts," these are further discussed below under Ground icings. A frost belt is essentially a ditch or cleared strip of land upstream or upslope from the icing problem area. If organic soil and vegetative cover are removed and

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the area is kept clear of snow during the first half of the winter, deep seasonal frost will act as a dam to water seeping through the ground, forcing it to the surface where it will form an icing upstream or upslope from the belt. In applying this technique to a drainage channel, a belt is formed by periodically cutting transversely into the ice to cause the bottom of the ice cover to lower and merge with the bed. In this way, the icing is induced to form away from the bridge or culvert entrance being protected.

(2) Ground icings. The most successful methods of preventing ground icings involve drainage. Other procedures depend on preventing formation in one location by inducing formation elsewhere. Principal methods are cited below.

(a) Surface drainage. This may be accomplished by a network of ditches located so as to drain the soil surface in the region of icing development. Ideally these ditches will be sited in compliance with airfield/heliport lateral safety clearance criteria and be narrow and deep so as to drain the soil to an appreciable depth and to expose only a small surface area to heat loss to the atmosphere. In some cases, these drainage ditches are covered and insulated to maintain flow in winter. Open ditches can be as narrow as 1 ft (0.3 m) or, if insulated, about 3 ft (1 m) wide by 3 ft deep.

(b) Subsurface drainage.[5] In seasonal frost areas, subsurface drainage systems are more suitable than surface drains because of their better resistance to freezing and ability to intercept more groundwater. They are not suitable for use in permafrost areas due to freezing. Subsurface drainage systems can use any of numerous types of perforated, slotted or open-jointed pipe materials (see Guide Specification for Military Construction MCGS 02502[15]) most commonly in 6-in.-diameter size. Improved resistance to freezing can be obtained by placing an insulation layer above the usual granular backfill surrounding the subdrain but beneath the final native soil backfill. In any case, water collected must be conveyed to an outlet away from the area being protected even if it forms an icing at that point.

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(c) Insulation of ground. In some cases ground icings can be prevented by insulating the ground in areas where deep seasonal frost penetration forms a dam, blocking groundwater flow. Insulating material may be snow, soil, brush or peat. This technique may merely shift the location where an impervious frost dam occurs. It is essential that the insulation of the ground extend under the pavement being protected to assure that groundwater flow is maintained past it. Otherwise, seasonal frost penetration under a snow-free airfield pavement would act as a frost dam and cause an icing to form upslope from the area. Suitable insulation materials for pavements are available and have been used.

(d) Frost belts. Successful use of frost belts requires careful siting, planning and maintenance. They may be either permanent or seasonal. The permanent type belt, as mentioned in paragraph 3-5b (1)(c) for control of river or stream icings, is a strip of land cleared of organic soil and vegetation, extending across a slope normal to the direction of seepage flow. Seasonal frost beneath this belt, merging with or approaching some impervious base, causes an icing to form upslope from the belt location. The belt must be long enough to prevent the icing from extending around the ends of the belt and approaching the airfield or other areas being protected. Such a belt is usually about 2 to 3 ft (0.6-0.9 m) deep and 10 to 15 ft (3 to 5 m) wide. Spoil from the excavation is placed as a low ridge on the downslope side of the belt (see Fig. 3-1).
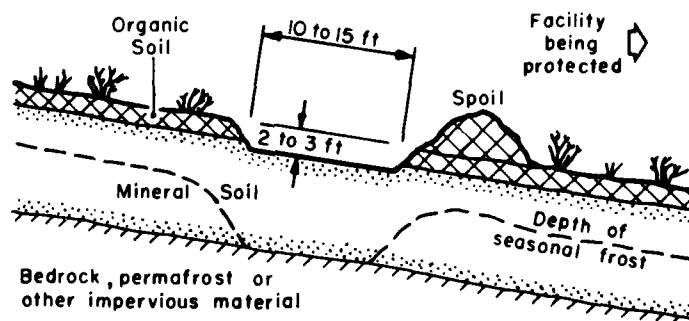

Figure 3-1 Typical cross section of a frost belt installation.[18]

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The shape of the frost belt depends on the topography; often it is slightly convex downslope, or made of two straight segments meeting at an angle of 160-170 degrees on the upslope side of the belt. Sometimes more than one belt is needed, the belts being arranged parallel to each other with their spacing depending on the channel slope. Permanent frost belts require attention to avoid degradation of the permafrost table underneath as the insulation of the ground has been reduced by removing the organic soil and vegetative cover. After a few years, the permafrost table may lower so much that the seasonal frost penetration in the winter will not reach it. In such a case, seepage flow in the soil would not be stopped at the belt; an icing does not develop at the belt but occurs instead downslope at the airfield or other facility intended to be protected. This can be avoided by covering the belt area in the spring with an insulating material and removing it in the fall before the onset of winter frosts. The belt must be kept clear of snow through the first half of the winter to permit rapid and deep seasonal frost penetration. Seasonal type frost belts[12] are free from most maintenance requirements associated with the permanent type and are much simpler and more economical to construct. Instead of preparing a ditch in the ground, one merely clears a strip of snow at the desired belt location and keeps it free of snow during the first half of the winter. The cleared snow is piled downslope of the belt, forming a ridge. The chief advantage of the seasonal belt is that it is less likely to degrade the underlying permafrost; this objective can be further assured by relocating the belt up- or downslope in successive winters. A disadvantage of the seasonal belt is that seasonal frost penetrates below it more slowly, owing to the high specific heat of the wet organic soil and the insulation afforded by the vegetation left in place. It therefore takes longer for a frost dam to form and stop the flow of seepage water. This may permit formation of some icing at the downslope protected area early in the winter before the seasonal frost belt attains full effectiveness. Frost belts have not been widely accepted because of neglect in placement of summer insulation and priority attention to snow removal from pavements rather than from frost belt areas in the winter. Frost belts are much easier to maintain in locations where the impervious base which restricts groundwater flow is other than permafrost, and thus is not subject to degradation.

      (e) Earth embankments and impervious barriers. Ground icing

formation can also be prevented by use of earth embankments combined with impervious barriers to groundwater flow. These are placed well away from the area to be protected and function similarly to frost belts in that they dam seepage flow through the soil, causing it to rise to the ground surface where it freezes to form an icing. In southern permafrost zones where permafrost is close to freezing temperatures, embankments may cause the permafrost to melt, leading to subsidence. Methods of developing the impervious barrier include trenching across the slope down to the impervious stratum, filling the trench with clay and then driving a row of sheet piling through it extending several feet above the surface to aid in ponding (see Fig. 3-2a).

Other expedients include use of plastic membrane instead of piling (see Fig. 3-2b) or burial of horizontal air duct pipe (12 to 18 in.; 0.3 to 0.5 m), located usually 4 to 6 ft (1.2 to 1.8 m) below the bottom of the embankment.
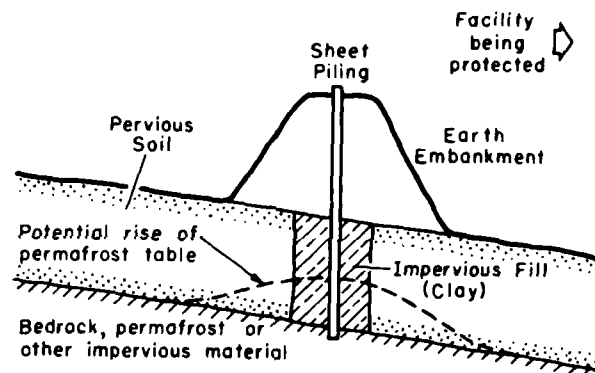
a. Sheet piling barrier.
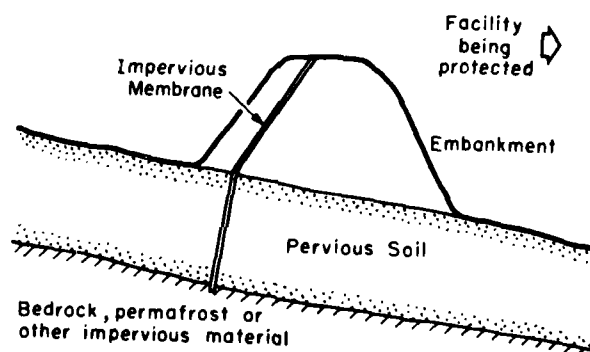
b. Plastic membrane barrier.

Figure 3-2. Earth embankments with impervious barriers.[18]

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Vertical air shafts from the horizontal ducts permit cold winter air
to permeate the system, removing heat from the ground and freezing the soil
beneath the embankment to create an impervious barrier. The vertical air
shafts are sealed in the summer to prevent excessive thawing in the soil.
A problem which has arisen in some duct installations is that if they are
not completely watertight infiltrated water will freeze in them, causing an
obstruction, generally difficult to clear. As this type installation would
obstruct seepage flow year-round, rather than just in winter, gated open-
ings must be provided to allow accumulated water to flow downslope during
the summer. The openings are closed all winter to assure that the icing
will form upslope from the embankment. An innovation is use of a steel
mesh grid with apertures 8 to 32 in. (0.2 to 0.8 m) square. These permit
passage of water when the air is warm, but gradually freeze until a block-
age forms in subfreezing weather. Grids must be removed in the summer to
avoid debris accumulation.

SECTION 4. ENVIRONMENTAL IMPACT CONSIDERATIONS

4-1. NATIONAL ENVIRONMENTAL POLICY. The National Environmental Policy Act
of 1969 (NEPA), approved 1 January 1970, sets forth the policy of the
Federal Government, in cooperation with State and local governments and
other concerned public and private organizations, to protect and restore
environmental quality. The Act (Public Law 91-190) states, in part, that
Federal agencies have a continuing responsibility to use all practicable
means, consistent with other essential considerations of national policy,
to create and maintain conditions under which man and nature can exist in
productive harmony. Federal plans, functions and programs are to be
improved and coordinated to 1) preserve the environment for future genera-
tions, 2) assure safe, healthful, productive, and aesthetically pleasing
surroundings for all, 3) attain the widest beneficial uses of the environ-
ment without degradation, risk to health or safety or other undesirable
consequences,...and 4) enhance the quality of renewable resources and
approach the maximum attainable recycling of depletable resources. All
Federal agencies, in response to NEPA, must be concerned not just with the
impact of their activities on technical and economic considerations but
also on the environment.

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4-2. EXECUTIVE ORDERS. Executive Order 11514 of 5 March 1970 states that, "the Federal Government shall provide leadership in protecting and enhancing the quality of the Nation's environment to sustain and enrich human life. Federal agencies shall initiate measures to direct their policies, plans, and programs so as to meet national environmental goals." Executive Order 11752 of 17 December 1973 enunciates its purpose "to assure that the Federal Government in the design, construction, management, operation, and maintenance of its facilities shall provide leadership in the nationwide effort to protect and enhance the quality of our air, water, and land resources...."

4-3 ENVIRONMENTAL CONSIDERATIONS IN DOD ACTION. DoD Directive 6050.1, 19 March 1964, establishes policy of the Department of Defense, as a trustee of the environment, to demonstrate leadership and carry out its national security mission in a manner consistent with national environmental policies and host country environmental standards, laws, and policies. The directive requires that DoD components shall:

"1. Assess at the earliest practical stage in the planning process and in all instances prior to the first significant point of decision, the environmental consequences of proposed actions.

"2. Review those continuing actions initiated prior to enactment of P.L. 91-190 for which the environmental consequences have not been assessed and ensure that any of the remaining actions are consistent with the provisions of the directive.

"3. Utilize a systematic interdisciplinary approach in planning and decision making.

"4. Prepare and process under the criteria contained in the directive a detailed environmental impact statement on every recommendation or report on proposals for legislation and other major defense actions which are expected to be environmentally controversial or could cause a significant effect on the quality of the human environment.

"5. Study, develop and describe appropriate alternatives to the recommended course of action in any proposal which involves unresolved conflicts concerning alternative uses of available resources."

4-4. U.S. ARMY ENVIRONMENTAL QUALITY PROGRAM. C2, AR 200-1,[1] outlines the Army's fundamental environmental policies, management of its program, and its various types of activities, one of which, water resources management, includes minimizing soil erosion and attendant pollution caused by rapid

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runoff into streams and rivers. The overall goal is to "plan, initiate, and carry out all actions and programs in a manner that will minimize or avoid adverse effects on the quality of the human environment without impairment of the Army mission." A primary objective is to eliminate the discharge of pollutants produced by Army activities. Provision of suitable surface drainage facilities is necessary in meeting this objective. Among the types of actions listed as requiring close environmental scrutiny because they may either affect the quality of the environment or may create environmental controversy are the following which pertain to surface drainage in the Arctic and Subarctic.

    a. Real estate acquisition, disposal, and out-leasing.

    b. Proposed construction of utilities including drainage systems.

    c. Constructing or installing open channels, ditches, culverts, or other barriers that might obstruct migration, passage or free movement of fish and wildlife.

    d. Closing or limiting areas, such as roads or recreational areas, that were previously open to public use.

    e. Proposed construction on flood plains or construction that may cause increased flooding, erosion or sedimentation activities.[30]

    f. Channelization of streams, diversions or impoundment of water.

    g. Proposed construction of pipelines and other drainage structures.

4-5. U.S. AIR FORCE ENVIRONMENTAL QUALITY PROGRAM. AFR 19-1[24] enunciates Air Force policy in compliance with above-stated NEPA executive orders and DoD directives. Procedures outlined are similar to those described for Army installations. AFR 19-2[25] establishes policies, assigns responsibilities, and provides guidance for preparation of environmental assessments and statements for Air Force facilities. Air Force Pamphlet 19-5[26], 15 October 1975, "Environmental Quality Control Handbook," lists storm drainage among problem areas at Air Force installations. Sources and types of pollutants, pollution effects and control measures are discussed.

4-6. ENVIRONMENTAL IMPACT ANALYSIS. A comprehensive reference, "Handbook for Environmental Impact Analysis,"[23] was issued in September 1974. This document, prepared by the Corps of Engineers Construction Engineering Research Laboratory (CERL), presents recommended procedures for use by Army personnel in preparing and processing environmental impact assessments (EIA) and environmental impact statements (EIS). The procedures list step-by-step actions considered necessary to comply with requirements of NEPA

and subsequent guidelines. These require that all Federal agencies use a systematic and interdisciplinary approach to incorporate environmental considerations into their decision making process. Eight major points to be covered by environmental impact statements are listed as follows:

"1. A description of the proposed action, a statement of its purpose, and a description of the environmental setting of the project.

"2. The relationship of the proposed action to land-use plans, policies, and controls for the affected area.

"3. The probable impact of the proposed action on the environment.

"4. Alternatives to the proposed action, including those not within the existing authority of the responsible agency.

"5. Any probable adverse environmental effects that cannot be avoided (summarizing the unavoidable parts Point 3 and, separately, how avoidable parts Point 3 will be mitigated).

"6. The relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity.

"7. Any irreversible and irretrievable commitments of resources (including natural and cultural as well as labor and materials).

"8. An indication of what other interests and considerations of Federal policy are thought to offset the adverse environmental effects identified."

4-7. ENVIRONMENTAL EFFECTS OF SURFACE DRAINAGE SYSTEMS. Such facilities in the Arctic or Subarctic could have either beneficial or adverse environmental impacts affecting water, land, ecology, and socio-economic (human and economic) considerations. Despite low population density and minimal development, the fragile nature of the ecology in the Arctic and Subarctic has attracted the attention of environmental groups interested in preserving these unique assets. Effects on surrounding land and vegetation may cause changes in various conditions in the existing environment, such as surface water quantity and quality, groundwater levels and quality, drainage areas, animal and aquatic life, and land use. Proposed systems may also have social impacts on the community, requiring relocation of military and public activities, open space, recreational activities, community activities and quality of life. Environmental attributes related to water could include such items as erosion, aquifer yield, flood potential, flow or temperature variations (the latter affecting permafrost levels and ice jams), biochemical oxygen demand, and content of dissolved oxygen, dis-

solved solids, nutrients and coliform organisms. These are among many
possible attributes to be considered in evaluating environmental impacts,
both beneficial and adverse, including effects on surface water and ground-
water. Various methods are discussed for presenting and summing up the
impact of these effects on the environment.

4-8. DISCHARGE PERMITS. The Federal pollution abatement program requires
regulatory permits for all discharges of pollutants from point sources
(such as pipelines, channels or ditches) into navigable waters or their
tributaries. This requirement does not extend to discharges from separate
storm sewers except where the storm sewers receive industrial, municipal
and agricultural wastes or runoff, or where the storm water discharge has
been identified by the EPA Regional Administrator, the State water pollu-
tion control agency or an interstate agency as a significant contributor of
pollution. Federal installations, while cooperating with and furnishing
information to State agencies, do not apply for or secure State permits for
discharges into navigable waters.

4-9. EFFECTS OF DRAINAGE FACILITIES ON FISH.[40] Natural drainage channels
in many locations are environmentally important to preservation of fish re-
sources. Culverts, ditches and other drainage structures constructed along
or tributary to these fish streams must be designed to minimize adverse
environmental effects. Culvert hazards to fish include high inverts,
excessive velocities, undersized culverts, stream degradation, failed or
damaged culverts creating obstructions, erosion and siltation at outlets,
blockage by icings, and seasonal timing and methods of drainage construc-
tion. Consultation with Federal and State fish and wildlife agencies will
provide guidance on probable effects and possible expedients to mitigate
them. Special concern will be given to anticipated conditions during fish
migration season. Certain conditions are discussed below.

a. High inverts. Fish passage is impossible when the culvert outlet
is set too high, exceeding jumping ability of the fish and creating a spill
velocity exceeding the swimming capability of the fish. Causes can be
survey or design error, easier installation, or unexpected degradation of
the downstream channel after culvert installation.

b. High velocities in culverts. These prevent fish from swimming
upstream. Factors affecting velocity include the culvert's area, shape,
slope, and internal roughness, and inlet and outlet conditions. Some
increases in velocity result from the culvert alignment being straight in

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lieu of the natural stream's meander. Tailwater elevation, the water level in the downstream channel at the culvert outlet, should be about D/8 where D is the pipe diameter or pipe arch rise, but not less than 2.5 in. This minimum should be set with due consideration to recommendations of local fishery biologists.

c. Undersized or failed culverts: These can cause overtopping and washout of an embankment and destroy a fish resource by release of large amounts of sediment and debris.

d. Erosion along drainageways or at outlets.[30] Additional sediment from uncontrolled erosion can adversely affect fish. Causes can be high velocities, high inverts, undersized culverts, inadequate bank protection and lack of suitable culvert endwalls.

e. Channel filling. Covering an extensive reach of stream bottom decreases the area most suitable for spawning, depleting renewal of stocks. Proper biological input in siting and designing drainageways will avoid this problem.

f. Culvert installation. Scheduling culvert excavation, channel diversion, and channel crossings by equipment should avoid times of the year which are critical to the fish cycle.

g. Control of icings. Thawing devices such as electrical cables[20] or steam lines, essential to any design where there is ice buildup, should be in operation to assure freedom from ice blockages during the spring migration period.

SECTION 5. DESIGN PROCEDURES FOR STORM DRAINS

5-1. GENERAL. The type and capacity of storm drain facilities required to accomplish economically the general objective outlined in paragraph 1-3 are determined primarily by the promptness with which design storm runoff must be removed to avoid serious interruption of traffic or hazardous conditions on important operational areas, and to prevent serious damage to pavement subgrades. It is presumed that all phases of site reconnaissance have been carefully completed and that information is available that shows topography and natural drainage patterns, groundwater conditions, seasonal frost levels, and permafrost levels, as discussed in TM 5-852-2.[11] Regions not adequately mapped and about which little, if any, factual information is available can be evaluated by application of airphoto techniques as described in TM 5-852-8.[13] Even though rainfall is light in arctic and sub-

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arctic regions, drainage is an important factor in the selection of an air-field or heliport site and subsequent planning and development. The planner[2] should be cognizant of several features related to drainage to assure a successful design. Some of these are as follows:

a. Sites should be selected in areas where cuts, or the placement of base course fills, will not intercept or block existing natural drainage-ways or subsurface drainageways. Adequate provision should be made for the changed drainage conditions.

b. Areas with fine-grained frost-susceptible soils should be avoided if possible. In arctic and subarctic regions most soils are of single grain structure with only a very small percentage of clay. Since the cohesive forces between grain particles are very small, the material erodes easily. Fine-grained soil profiles may also contain large amounts of ice lenses and wedges when frozen.

c. If the upper surface of the permafrost layer is deep, design features of a drainage system can be similar to those used in frost regions of the continental United States if due provisions are made for lower temperatures.

d. The avoidance, control, and prevention of icings are discussed in Section 3.

e. The flow of water in a drainage channel accelerates the thawing of frozen soil and bedrock. This may cause the surface of the permafrost to dip considerably beneath streams or channels that convey water, and may result in thaw of ice such as that contained in rock fissures and cracks. The latter could develop subsurface drainage channels in bedrock. Bank sloughing and significant changes in channel become prominent. Sloughing is often manifested by wide cracks paralleling the ditches. For this reason, drainage ditches should be located as far as practicable from runway and road shoulders and critical structures.

f. In many subarctic regions, freeing drainage channels of drifted snow and ice becomes a significant task before breakup each spring. In these areas it is advantageous to have ditch shapes and slopes sufficiently wide and flat to accommodate heavy snow-moving equipment. In other locations where flow continues year-round, narrow deep ditches are preferable to lessen exposed water surface and avoid icings.

g. Large cut sections should be avoided in planning the drainage lay-out. Thawed zones or water-bearing strata may be encountered and later

cause serious icings. Vegetative cover in permafrost areas should be preserved to the maximum degree practicable; where disturbed, it should be restored as soon as construction permits.

h. Fine-grained soils immediately above a receding frost zone are very unstable; consequently much sliding and caving is to be expected on unprotected ditch side slopes in such soils.

i. Location of ditches over areas where permafrost lies on a steep slope should be avoided if possible. Slides may occur because of thawing and consequent wetting of the soil at the interface between frozen and unfrozen ground.

j. Provisions should be made for removal and disposal or storage of snow and ice with due consideration to control of snowmelt water. Drainage maintenance facilities should include heavy snow-removal equipment and electric cables with energy sources or a steam boiler with accessories for thawing structures that become clogged with ice. Pipes or cables for this purpose are often fastened inside the upper portions of culverts prior to their placement.

k. Usually inlets to closed conduits should be sealed before freeze-up and opened prior to breakup each spring.

5-2. GRADING. Proper grading is a very important factor contributing to the success of any drainage system. The development of grading and drainage plans must be most carefully coordinated. In arctic and subarctic regions, the need for elimination of soft, soggy areas cannot be overemphasized.

5-3. TEMPORARY STORAGE. Trunk drains and laterals should have sufficient capacity to accommodate the project design runoff. Supplementary detention ponds upslope from drain inlets should not be considered in drainage designs for airfields or heliports in the Arctic and Subarctic. Plans and schedules should be formulated in sufficient detail to avoid flooding even during the time of actual construction.

5-4. COMPUTATION OF STORM DRAIN CAPACITIES. Appendix A is a design example for drainage facilities to serve a typical portion of an airfield in a subarctic region. A separate design example for a typical airfield drainage system in an arctic region is not included in this report as it would follow identical methodology but with two simplifications, as follows: (1) layout would be relatively more austere, usually limited to an aircraft parking apron and a single runway with no parallel taxiway, and

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(2) as infiltration would be zero, the rate of supply would be the design rainfall rate plus snowmelt. In the subarctic design, the main procedures and steps followed in the determination of storm drain or culvert capacities are given in a step-by-step outline with tables as the design example. It is assumed that the airfield in the Subarctic has a 1-hour rainfall of 0.6 in. plus 0.1 in. runoff from snowmelt, or a total of 0.7 in. (18 mm), a mean annual temperature of about 25°F (-4°C), the design storm frequency as for most airfields is 2 years, and the infiltration rate for unpaved areas is 0.2 in. (5 mm) per hour. Standard supply curve numbers to be used are therefore 0.7 and 0.5 for paved and turfed areas, respectively. Details are outlined in Appendix A.

SECTION 6. DESIGN COMPUTER PROGRAMS

6-1. GENERAL. The hydrologic criteria for drainage designs, as outlined in Section 2 of this report and illustrated in Appendix A, are readily used with a family of convenient interrelated design charts, for which development of a computer program is not considered warranted. There are, however, several computer programs available for solving engineering problems associated with the design of drainage systems, as discussed in the following paragraphs.

6-2 HYDRAULIC DESIGN PROBLEMS. "CORPS" is a time-sharing system developed for the Corps of Engineers computer at the Waterways Experiment Station in Vicksburg, Mississippi, with a library of computer programs, principally in the field of hydraulics. Corps offices nationwide have telephone remote terminal access to "CORPS." Use of this computer system is fully explained in step-by-step procedures suited to engineering personnel communicating in discipline-oriented language. Among available hydraulic programs useful to drainage designers are the following.

H6001   Geometric elements of trap., tria., or rect. channel
H6002   Geometric elements of circular conduit
H6005   Geometric elements of a natural channel
H6110   Normal depth-trap., tria., or rect. section-Manning formula
H6111   Normal depth and velocity-circular conduit-Manning formula
H6112   Normal discharge-Manning formula
H6140   Critical depth and velocity for trap., tria., and rect. section
H6141   Critical depth and velocity for circular conduit

H6201   Friction slope-any flow sect-Manning,Chezy or Colebrook-White

H6208   Flow profile-circ. cond-Manning,Chezy,or Colebrook-White form

H7220   Erosion at culvert outlets and riprap requirements

Details on these and other hydraulic design programs and their use are available from the Hydraulic Analysis Division of the Waterways Experiment Station.

6-3. QUALITY OF STORM WATER RUNOFF. In developed areas, planners, designers and operators of storm water drainage systems are often required to determine quantities of storm water runoff and evaluate its quality as an important component in overall condition of an area or watershed. Two computer models, designed principally for urban areas, are available. These are "STORM,"[16] developed by the Hydrologic Engineering Center of the Corps of Engineers, and "SWMM"[27] (Storm Water Management Model), developed for the Environmental Protection Agency.

SECTION 7. GUIDELINES FOR DESIGN OF STORM DRAINS
IN THE ARCTIC AND SUBARCTIC

7-1. GENERAL. TM 5-820-3[6] provides general design criteria for drainage and erosion control structures commonly used for airfields and heliports. Certain of the principles used in design are particularly applicable to drainage facilities in arctic and subarctic regions. These and others which are most important for arctic and subarctic drainage are discussed in this section of the report. Although this report is directed primarily to the subject of storm drain design, it is also applicable to design of culverts and open ditches, and the other conventional but important types of drainage structures.

7-2. MATERIALS. Specifications for drainage materials are given in Guide Specification for Military Construction MCGS 02501[14] and for subdrainage materials in MCGS 02502[15]. Selection of suitable types for specific projects will be based on design requirements - hydraulic, structural, and durability - and economics for the specific drainage installation. In the Arctic and Subarctic, the flexible thin-walled pipe materials - corrugated metal (galvanized steel or clad aluminum alloy) - have been most widely

used for drainage applications because of their availability, and dependability of jointing. Heavier rigid type pipe, reinforced and nonreinforced concrete, particularly with recently developed flexible gasketed joints, and the newer types of plastic pipe are used under certain conditions in the Subarctic.

7-3. STRUCTURAL DESIGN. Airfield and heliport culvert and storm drain structural requirements – pipe wall minimum thickness or gage – are usually detrmined based on minimum amounts of protective earth or pavement cover above the pipe and the maximum aircraft gear loadings to be accommodated. These structural design criteria are given in Table I of TM 5-820-3[6]. Table II of that manual lists the minimum cover requirements to protect culverts and storm drains in seasonal frost areas from frost heave or from water freezing in the pipe.

7-4. SERVICE LIFE AND DURABILITY. These factors will influence drainage material selection. Although the commonly used drainage materials are acceptable in most soil and water environments, there are environmental conditions which limit their service life. Principal among these detrimental factors are corrosion, abrasion, and freezing and thawing action. Protective or periodic maintenance measures to prolong service life where conditions are adverse are difficult, costly, and limited in effectiveness. Often the most practical measure is periodic removal and replacement of damaged or failed drainage components. While this can be readily accomplished under nontraffic shoulders or other less important airfield areas, designs should be based on avoidance of replacement under primary runways, important pavement intersections or high fills. A recent report, cited as reference 32, gives guidelines for the selection of durable materials and protective treatments for various adverse environments. The main adverse situations are briefly cited below. This is a complex subject, addressed only in generalities in this report.

a. Corrosion. Common types of corrugated metal pipe generally corrode when the soil or water is highly acid or alkaline (pH below 5 or above 9) and high electrical conductivity (low soil resistivity) conditions prevail. Mining operations, storage or use of chlorides for snow- and ice-melting, peat or cinder deposits, and salt water in coastal environments

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are common causes of metal pipe deterioration. Concrete is also vulnerable to acids and certain chemicals (sulfates, chlorides, carbonates) in soils. Plastic, stainless steel or clay pipe or special newly developed protective coatings available for the various pipe materials may be required for use in particularly aggressive environments.

b. Abrasion. This process, more common in culverts than in storm drains, is the wearing down or grinding away of metal, concrete, plastics, clay and other pipe materials and their protective coatings. It occurs when water laden with sand, gravel, stones, ice or other debris flows through, particularly if the flow has a high velocity and if heavy runoff events occur frequently and with long duration. Where severe abrasion is anticipated, extra thickness of pipe material can be provided, especially along the bottom where wear from bedload moveme.. concentrated. In some places, abrasive sediment can be removed by proviuing upstream debris control structures.

7-5. SHAPE OF DRAINAGE STRUCTURES. The required hydraulic capacity of a storm drain or culvert can be provided by any of several configurations. While they are usually circular, other factors such as limited headroom, debris accumulation, icing formation, fish passage, fill height, and hydraulic performance may dictate selection of another shape of hydraulically equal capacity - rectangular, oval, arch or multiples. Similarly, options are available in the shape of lined or unlined open drainage channels, ditches, or swales with adherence to airfield or heliport lateral safety clearance criteria.

7-6. MAINTENANCE. Access for mainte.. ne equipment and personnel is necessary for major drainage channels, debris control barriers and icing control installations. Structures should be periodically inspected, particularly before fall freezeup and after annual spring thaw-breakup periods.

7-7. JOINTING. Disjointing, leakage or failure in pipe joints can occur, especially where drainage lines are subject to movement caused by backfill settlement, live loads, or frost action. Flexible watertight jointed pipe is available (see Guide Specification MCGS 02501[14]) for use in such situations. Most watertight joints rely on use of close tolerance pipe ends connected over a closely fitting gasket.

7-8. END PROTECTION. End structures, factory-made or constructed in the field, are attached to the ends of storm drains or culverts to provide structural stability, hold the fill, reduce erosion and improve hydraulic characteristics. A drain projecting beyond the slope of an airfield or roadway embankment is a hazard and subject to damage or failure caused by ice, drift or the current. Drain ends can be mitered to fit embankment slopes or provided with prefabricated flared end sections. Headwalls and wingwalls to contain pipe ends are often constructed, usually of concrete, to meet the several design requirements including provision of weight to offset uplift or buoyancy and to inhibit piping (paragraph 7-10). Headwalls or wingwalls should be oriented or skewed to fit the drain line for maximum hydraulic efficiency and to lessen icing formation and drift or debris accumulation. The effect of pipeline entrance design on hydraulic efficiency of drainage systems is discussed in TM 5-820-4[7]. A properly shaped culvert entrance can be an important factor in reducing ponding at an inlet which can wash out an airfield or roadway embankment.

7-9. ANCHORAGE AND BUOYANCY.[33] Forces on a drain line inlet during high flows, especially during spring breakup, are variable and unpredictable. Currents and vortexes cause scour which can undermine a drainage structure and erode or fail embankments. These conditions are accentuated in the Arctic and Subarctic by accumulated ice and debris. Corrugated metal pipe sections, being thin-walled and flexible, are particularly vulnerable to entrance distortion or failure. Ends can be protected by providing secure heavy anchorage. This could be a concrete or grouted rock endwall or slope pavement. Rigid type pipe with its shorter sections is subject to disjointing if undermined by scour unless provided with steel tiebars to prevent movement and separation. Buoyant forces must be determined for possible conditions such as blockage of a drainage line end by ice or debris, flow around the outside of a pipe or, in coastal locations, tidal effects. These forces must be counteracted by adequately weighting the line, tying it down, or providing vents. Catastrophic drainage failures have resulted from failure to safeguard against such occurrences, even in temporary situations during construction.

7-10. PIPING. Piping is the result of seepage along the exterior of a drain line or culvert which removes backfill material, forming a pipe-like void the full length of the line. Provision of watertight joints (and, if warranted, locked or welded seams in metal pipe) will also reduce exfiltration, a source of seepage flow. The washout of fine-grained soils along the pipeline can ultimately cause its collapse and loss of the overlying embankment. Measures taken to prevent piping include provision of impervious backfill or a large headwall at the upstream end of the line or installation of seepage-preventive metal or concrete bulkheads or collars circling the entire periphery of the drain. The availability of plastic filter cloth which will permit controlled seepage without migration of fine-grained soils provides another useful design expedient to limit piping.

7-11. DEBRIS AND ICING CONTROL. It is essential to control debris and icing to achieve desired hydraulic and structural performance and to avoid damages and operational interruption from flooding and uncontrolled icings. (See also Section 3, Icings.) The debris problem can be solved by providing a structure large enough to pass the material or by retaining it at a convenient adequate storage and removal location upstream from the drainage structure.

7-12 TIDAL AND FLOOD EFFECTS. Airfields, with their requirements for large level areas, are often sited on coastal or alluvial floodplains where their drainage systems are subject to tidal and stream flood effects. In arctic and subarctic regions, ice jam and spring break-up dynamic forces and flood heights create major problems, including stream migration, which can adversely affect airfield embankments and protective levees, degrade permafrost, and shift or block drainage outlets. Stream meander control is difficult and costly, especially in the Arctic. Flap gates may be required to prevent backflow into drainage systems, a situation particularly undesirable in tidal or brackish water locations due to corrosive action on drainage pipelines. These gates require a high level of maintenance to assure their operation despite ice, debris, sand or silt accumulation.

7-13. FISH PASSAGE. The need to accommodate seasonal fish migration along certain streams should be determined through early coordination with

Federal and state fish and wildlife agencies. In some locations fish barriers may be required to prevent migration of undesirable fish species into upstream water bodies. See paragraph 4-9, "Effects of Drainage Facilities on Fish."

7-14. EROSION CONTROL. Drainage and erosion control are discussed in TM 5-820-3.[6] Erosion control is important, not just in the design and maintenance of airfields, heliports, and other facilities, but also during construction, when special care must be taken to minimize erosion and siltation from denuded and excavated areas. Temporary siltation basins, check dams, and straw-bale sediment traps should be considered for use in drainage ditches and above drain inlets. Vegetative cover should be reestablished as soon as practicable (see TM 5-830-2,[9] "Planting Turf").

7-15. INSTALLATION. Pipe construction in the Arctic and Subarctic, as in other regions, requires shaped bedding and systematic, layer-by-layer backfilling and compaction, and maintaining equal heights of fill along both sides of the pipe. Many culvert and storm drain failures during construction are caused by operating equipment too close to pipe, or failure to remove large projecting stones from backfill near the pipe, or inadequate caution in handling frozen backfill material.

7-16. SAFETY REQUIREMENTS. Fuel spillage must not drain into storm sewers or other underground conduits. Safe disposal of spilled fuel can be facilitated by providing ponding areas for drainage so that any spilled fuel can be removed from the surface. Curbs, gutters, and storm drains will not be provided for drainage around tank-car or tank-truck loading or unloading areas, or tanks in bulk fuel storage areas.

APPENDIX A: DESIGN EXAMPLE FOR ARCTIC AND

SUBARCTIC DRAINAGE

(See Section 5, para. 5-4)

a.   Preliminary Layout.   Prepare a map (scale 1 inch = 200 feet or
larger) showing the outline of runways, taxiways, parking aprons, paved
shoulders, facility areas, and roads.   Superimpose on this network 1-foot-
interval contours that will show the finished airfield or heliport.   Insure
that grades conform with current safety criteria as set forth in TM
5-803-4[2] for Army facilities or AFM 88-6, Chap. 1[8] for Air Force facilities
unless waiver approvals are secured.   If the airfield is also to be used
for civil aviation, coordinate the site selection with the District Airport
Engineer of the Federal Aviation Administration and the State Aviation
Agency.   Indicate locations of test pits, soil borings, and probings, and
designate significant items clearly.

b.   Profiles.   Plot profiles of all runways, taxiways, helipads and
parking areas, so that elevations and controlling grades can be ascertained
for any point.

c.   Drain Outlets.   With general consideration of the limiting grade
elevations and feasible channels for the disposal of storm runoff and snow
melt, select locations that are considered most suitable for outlets of
drains serving various portions of the field.   With this information,
select a tentative layout for primary storm drains.   In general, the most
economical and efficient design is obtained by maximum use of open ditches
in preference to underground drains and by maintaining the steepest hydrau-
lic gradient feasible in the main trunk drain, while making laterals on
each side approximately equal in length, insofar as practicable.

d.   Cross-sectional Profiles of Intermediate Areas.   Assume lines for
cross-sectional profiles of intermediate areas, plot data showing control-
ling elevation, and indicate the tentatively selected locations for inlets
by means of vertical lines.   In some cases the projection of runways, taxi-
ways, helipads, or aprons should be shown in the profiles, to facilitate a
comparison of elevations of intermediate areas with those of paved areas.
Generally, one cross-sectional profile should follow each line of the

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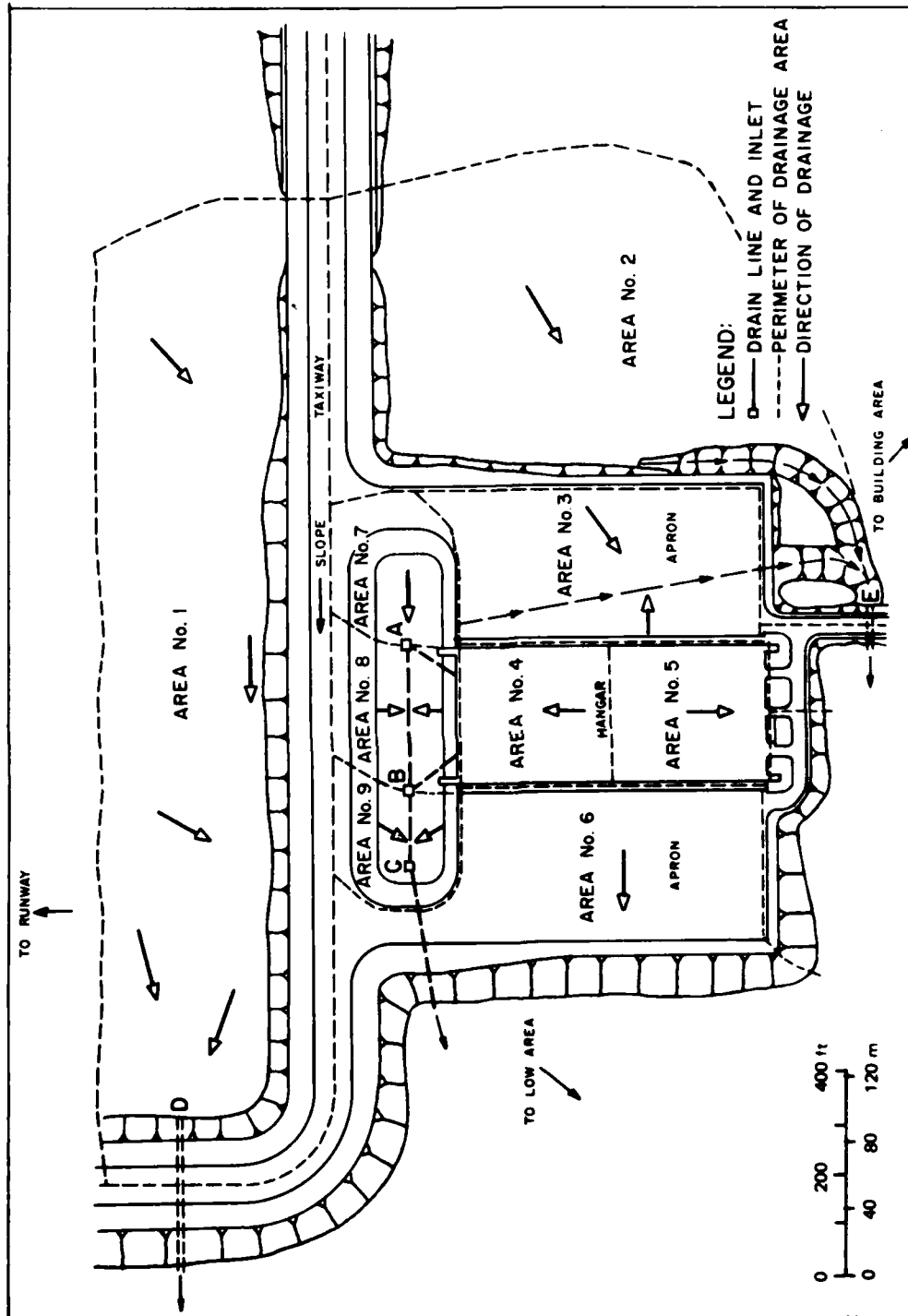
Figure A-1. Drainage problem: Airfield in subarctic region—hangar, taxiway and apron.

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underground storm drain system and others should pass through each of the
inlets at approximately right angles to paved runways, taxiways, helipads
or aprons.

e. Correlation of Controlling Elevations and Limiting Grades.
Beginning at points corresponding to controlling elevations, such as the
crown or edges of a runway, sketch in the ground profile from the given
points to the respective drain inlets, making the grades conform to limit-
ing slopes for the areas involved. Review the tentative grading and inlet
elevations and adjust the locations of drain inlets and grading details as
necessary to obtain the most satisfactory general plan.

f. Determination of Drainage Area. Using the completed grading plan,
sketch the boundaries of drainage areas tributary to the respective drain
inlets and compute the area of paved and unpaved areas tributary to the
respective inlets.

g. Ponding Basins. Avoid the use of ponding basins in arctic and
subarctic areas.

h. Average Retardance Coefficient. Assign values of n to various
turfed, bare, frozen ground, or paved subareas as explained in paragraph
2-6, RUNOFF, and compute average roughness factors for overland and channel
flow. See columns 6 and 20, and note 2 in Table A-1.

i. Average Slope. Estimate the average slope of overland and channel
flow conditions for each inlet drainage area using the data indicated on
the grading plan.

j. Effective Length. From the grading plan determine the effective
length of flow, giving due consideration to the occurrence of overland and
channelized flow. By use of Figure 2-3, convert the measured lengths of
flow to equivalent lengths of flow in 10-ft increments which correspond to
$S = 1.0\%$ and $n = 0.40$. For actual lengths exceeding 600 ft, divide by any
convenient factor and determine corrected length therefor, then multiply by
this factor to find the corrected length for the full distance. For
example, if actual length is 700 ft, determine corrected length for 350 ft
and multiply by 2. See also columns 8-10 of Table A-1.

k. Project Design Storm. By use of Figure 2-1 and the known geogra-
phic location of the airfield or heliport, select a project design storm of
the specified frequency of occurrence.

TABLE A-1. AIRFIELD DRAINAGE DRAIN-INLET CAPACITIES REQUIRED

Sheet ____ of ____ Date ____

For Paved Areas __0.7__
For Bare Areas _____
For Turfed Areas __0.5__
SUPPLY CURVE NOS.

PROJECT _Illustration_
LOCATION _Subarctic_
DIVISION OFFICE
DISTRICT OFFICE

DRAINAGE SECTION _TAXIWAY, HANGAR AND APRONS_

AREA NO.	DRAINAGE AREA (D.A.) IN ACRES				Average Roughness Factor "n"	Average Slope "S" In Percent	LENGTH L (FT.)			STANDARD SUPPLY CURVE NO. x D.A.				Weighted Supply Curve No. (Col.14 ÷ Col.5)	DRAIN-INLET CAPACITY			CRITICAL CONTRIBUTION TO SYSTEM		
	Paved (n=0.01)	Bare (n=)	Turf (n=0.30)	Total			Actual or Effective Length, Ft.	Equivalent L for n=.80 and Se=1.5	L Adopted for Selecting Diagrams	Paved Areas	Bare	Turf	Total		tc In Minutes	qd In c.f.s. Per Acre of D.A.	qd In c.f.s. (Col.17 x Col.5)	tc In Minutes	qd In c.f.s. Per Acre of D.A.	qd In c.f.s. (Col.20 x Col.5)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	4.25		16.10	20.35	0.24	1.2	300	170	630	2.98			8.05	0.54	95	0.25	5.1 D			1.6 D
					0.12	1.0	1650	460					11.03							
2	1.37		13.59	14.96	0.27	1.1	600	380	850	0.96			6.80	0.52	120+	0.17	2.5	20	0.11	1.6 D
					0.23	0.5	600	470					7.76							
3				4.42	0.01	1.0	250	10	30	3.09			3.09	0.70	10	1.95	8.6	15	1.47	6.5
					0.01	0.8	550	20										20	1.37	6.1 D
4				1.91	0.01	1.0	300	20	20	1.34			1.34	0.70	10	2.3	4.2	15	1.68	3.2 D
																		20	1.45	2.8
																		25	1.26	2.4
7	0.96		0.54	1.50	.11	2.0	300	60	60	0.67			0.27	0.63	13	1.02	1.5	15	1.02	1.5 D
													0.94					20	0.98	1.5
																		25	0.92	1.4
8	0.76		0.89	1.65	0.16	5.0	60	20	90	0.53			0.45	0.59	18	0.83	1.4	15	0.83	1.4 D
					0.10	1.3	300	70					0.98					20	0.82	1.3
																		25	0.80	1.3
9	0.80		0.54	1.35	0.13	1.0	60	20	60	0.56			0.27	0.62	13	1.02	1.4	15	1.02	1.4 D
					0.12	1.0	150	40					0.83					20	0.98	1.3
																		30	0.87	1.2

Drainage areas from figure A-1.

1. No ponding allowed in arctic and subarctic areas.

2. Average roughness factor "n" (Col. 6) for channel sections obtained from figure 2-4 assuming a hydraulic radius of 0.9 and a grass coefficient of 1.4.

3. Values indicated by "D" are used in design. (See table A-2.)

TABLE A-2 , AIRFIELD DRAINAGE
SIZE AND PROFILE OF UNDERGROUND STORM DRAINS
DRAINAGE SECTION: _TAXIWAY, HANGAR AND APRONS_

Sheet ___ of ___ Date _____ , 19___

SUPPLY CURVE NOS.
For Paved Areas __0.7__
For Bare Areas _____
For Turfed Areas __0.5__

PROJECT _Illustration_
LOCATION _Subarctic_
DIVISION OFFICE
DISTRICT OFFICE

INLET OR JUNCTION NUMBER	Distance, Feet – From Main Outlet	Distance, Feet – From Preceding Inlet	Critical Inlet	Critical Inlet Time, t_c, Min.*	Assumed Velocity In Pipe, Ft./Sec.	Drain Time, Min. – From Preceding Inlet	Drain Time, Min. – Accum. Total	Approx. t_c (Col. 5 + Col. 8)	Adopted t_c In Min.	Rate of Inflow Into Underground Drains, In C.F.S. Corresponding To Adopted Value or t_c (Column 10) – Inlet Number Area 9	Area 8	Area 7	Area 6	Area 5	Area 4	Area 3	Area 2	Area 1	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	450	0	A	13	–	0	0	13	15			1.5			1.6***				3.1
B	150	300	A	13	3.5	0	2	15	15		1.4	1.5			3.2				6.1
C	0	150	A	13	3.0	1	3	16	15	1.4	1.4	1.5			3.2				7.5
D	0	0	D	95	–	–	–	95	95									5.1	5.1
E***	250	0	E	10	0.5	9	9	19	20							6.1	1.6		7.7

Runoff from Areas 5 and 6 not needed for this illustration.

Rates of inflow are design values (D) from table A-1.

* From Col. 16, table A-1.

** Half of Area 4 drains to Inlet "A" and half to Inlet "B."

*** The critical time is the time it takes Area 3 to drain to point "E." Velocity shown is assumed velocity in the ditch from Area 3 to point "E."

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1. Snowmelt. Add an amount of 0.05 to 0.1 in./hr for snowmelt to the project design storm, paragraph k above.

m. Infiltration. If the airfield or heliport site is located in the Arctic, assume that the infiltration rate is zero. If in the Subarctic, determine average infiltration rates from local studies but not higher than 0.3 in./hr.

n. Standard Supply Curves. Standard supply curves for areas with zero infiltration loss will be the same as the standard rainfall plus snowmelt curves (see Fig. 2-2). Where infiltration losses occur, the standard supply curve number corresponding to a given standard rainfall plus snowmelt curve number is computed by subtracting the estimated 1-hour infiltration value from the 1-hour rainfall plus snowmelt quantity. See columns 11-14 of Table A-1.

o. Weighted Standard Supply Curve. Determine a weighted standard supply curve for the composite drainage area proportional to the standard supply curves for the various subareas. See column 15 of Table A-1.

p. Determination of Drain-Inlet Capacities. With reference to Figures 2-5 through 2-10, select the two graphs with supply curve numbers closest to the weighted standard supply curve determined above. The following procedure is carried through on both graphs and interpolated for the weighted standard supply curve. The critical duration of supply t_c (col. 16, Table A-1) and the maximum rate of runoff q_d (col. 17) for the individual inlet drainage area can be read directly from the graph for the given value of effective length. Values of t_c should not be less than the minimum values of 10 minutes for paved or bare areas and 20 minutes for turfed areas (see para. 2-6, Runoff). In order for the maximum rate of flow to be attained at a given point in a drainage system during a supply of uniform intensity, the storm must last long enough to produce a maximum rate of inflow into each upstream drain inlet and to permit the inflow to travel through the drain from the "critical inlet" to the given point. The duration of supply necessary for this purpose is referred to herein as t_c' and is given approximately by the equation

$$t_c' = t_c + t_d$$

in which t_c is the duration of supply that would provide the maximum design storm runoff from the area tributary to the critical drain inlet and t_d is the time required for water to flow from the critical drain inlet to the point under consideration. The critical inlet can normally be assumed to be the inlet located the greatest distance upstream from the given point. To simplify the determination of drain-inlet capacities, the computed values of t_c' can be rounded off to the nearest 5 minutes as shown in column 19 of Table A-1. The procedure for computing values of t_c' is described in TM 5-820-1.[4] Inspection of Figures 2-5 through 2-10 will show that for large values of effective length and low values of supply curve, the maximum rate of runoff is approximately constant after a duration of supply equal to t_c. Under these conditions, it will facilitate the design computations to use the constant value q_d for t_c duration of supply for all durations of supply in excess of t_c.

q. Computation of Pipe Sizes and Cover. The size and gradient of storm drain required to discharge storm runoff may be determined by using Mannings' formula or the charts provided in TM 5-820-1[4] or TM 5-820-4.[7] In any case, calculated capacities should be liberal to provide a safety factor against high flows during spring thaw and possible clogging due to icings (Section 3). It is recommended that minimum pipe diameter be at least 18 in. and preferably larger, even where the calculated runoff may require a smaller size. In selecting proposed inlet elevations and slope of pipelines, minimum cover required for the various pipe materials and strengths should be in accordance with TM 5-820-3.[6] At each site, prior to design, the suitability of embedment depths should be confirmed by field investigations.

r. Determination of Ditch Sizes. The ditch should be large enough to accommodate the storm runoff with liberal allowances for blockage or flow retardation due to formation of icings or accumulation of debris. The shape of ditches depends on airfield or heliport lateral clearance safety criteria, snow removal and storage practices, susceptibility to icings, erosion and debris control, and local environmental conditions.

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